

ENVIRONMENTAL IMPACTS OF MERCURY ON SOILS AND WATER RESOURCES  
IN SEKOTONG'S GOLD MINING VILLAGE IN LOMBOK ISLAND, INDONESIA

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จุฬาลงกรณ์มหาวิทยาลัย  
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เกาะลอมบอก ประเทศอินโดนีเซีย

นายโดนี มาริซี สีนากะ



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต  
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Field of Study	Environmental Management
Thesis Advisor	Associate Professor Wattasit Siriwong, Ph.D.
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โตนี มาริซี สีนากะ : ผลกระทบสิ่งแวดล้อมจากปรอทในแหล่งน้ำและดิน ของเหมืองทองคำหมู่บ้านชะกอตอง เกาะลอมบอก ประเทศอินโดนีเซีย (ENVIRONMENTAL IMPACTS OF MERCURY ON SOILS AND WATER RESOURCES IN SEKOTONG'S GOLD MINING VILLAGE IN LOMBOK ISLAND, INDONESIA) อ.ที่ปรึกษา วิทยานิพนธ์หลัก: รศ. วัฒนสิทธิ์ ศิริวงศ์ปริญญาเอก, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ศ. Mark G. Robson, 117 หน้า.

ปริมาณปรอทปนเปื้อนเฉลี่ย ( $\pm$  ค่าความคลาดเคลื่อนมาตรฐาน, SE) ในดินของหมู่บ้านกาวชูปุดาก ( $n=7$ ) มีค่าเท่ากับ  $0.392 \pm 0.170$  มิลลิกรัมต่อกิโลกรัม และ หมู่บ้านเทมโบวอง ( $n=7$ ) มีค่าเท่ากับ  $0.265 \pm 0.160$  มิลลิกรัมต่อกิโลกรัม ในบริเวณชะกอตองที่ทำขั้นตอนไซยาไนด์ชัน (cyanidation) ( $n=1$ ) พบค่าปรอทปนเปื้อนในดิน  $0.522$  มิลลิกรัมต่อกิโลกรัมและน้ำใต้ดิน  $0.170$  ไมโครกรัมต่อลิตรซึ่งสูงกว่าบริเวณที่ทำขั้นตอนอะมัลกามาชัน (amalgamation) ซึ่งพบว่าบริเวณดังกล่าวในดิน ( $n=8$ ) และในน้ำใต้ดิน ( $n=8$ ) พบค่าปนเปื้อนในดินเท่ากับ  $0.139 \pm 0.075$  มิลลิกรัมต่อกิโลกรัม และ น้ำใต้ดินเท่ากับ  $0.064 \pm 0.009$  ไมโครกรัมต่อลิตร สำหรับบริเวณที่ทำทั้งสองขั้นตอนไซยาไนด์ชันและอะมัลกามาชัน พบว่ามีค่าปรอทปนเปื้อนในดิน ( $n=1$ ) เท่ากับ  $1.175$  มิลลิกรัมต่อกิโลกรัม และ น้ำใต้ดิน ( $n=1$ ) เท่ากับ  $1.268$  ไมโครกรัมต่อลิตร ในน้ำใต้ดินของหมู่บ้านเทมโบวอง และ หมู่บ้านกาวชูปุดาก พบว่ามีร้อยละความเค็มเฉลี่ย ( $\pm$  SE) เท่ากับ  $1.09 \pm 0.43$  ปริมาณออกซิเจนละลายน้ำ (DO)  $1.72 \pm 0.35$  มิลลิกรัมต่อลิตร ค่าศักยภาพการเกิดออกซิเดชัน-รีดักชัน (ORP) ต่ำกว่า  $650$  มิลลิโวลต์ ค่าความเป็นกรด-ด่าง (pH) ในดินอยู่ในช่วง  $6.40-9.19$  ซึ่งมีความเป็นด่างสูงกว่าในน้ำใต้ดิน ซึ่งมีค่าในช่วง  $5.80-8.00$  ในดินของหมู่บ้านกาวชูปุดากพบว่ามีปริมาณความเข้มข้นของปรอทปนเปื้อน ความเป็นด่าง ความชื้น ความเค็ม และ ศักยภาพการเกิดออกซิเดชัน-รีดักชัน สูงกว่าหมู่บ้านเทมโบวอง โดยเฉพาะค่าศักยภาพการเกิดออกซิเดชัน-รีดักชันนั้นมีความแตกต่างอย่างมีนัยสำคัญที่ระดับความเชื่อมั่นน้อยกว่า  $0.01$  ในบริเวณเขตที่พักอาศัยที่ใช้เป็นพื้นที่เกษตรของทั้งสองพื้นที่ ( $n=6$ ) พบว่าปริมาณปรอทปนเปื้อนเฉลี่ย ( $\pm$  SE) ในน้ำใต้ดิน เท่ากับ  $0.447 \pm 0.385$  ไมโครกรัมต่อลิตร และ ในดินเท่ากับ  $0.455 \pm 0.198$  มิลลิกรัมต่อกิโลกรัม นอกจากนี้พบว่าปริมาณความชื้นในดินมีความสัมพันธ์เชิงบวกกับปริมาณความเข้มข้นของปรอทที่ปนเปื้อนในดิน ค่าสัมประสิทธิ์สหสัมพันธ์แบบสเปียร์แมน ( $r_s$ ) เท่ากับ  $0.798$  นอกจากนี้ พบว่ามีปริมาณปรอทปนเปื้อนในบริเวณปากแม่น้ำ  $1.764$  ไมโครกรัมต่อลิตร ซึ่งสูงเกินกว่ามาตรฐานกำหนดขององค์กรพิทักษ์สิ่งแวดล้อม สหรัฐอเมริกา (US.EPA) กำหนดไม่เกิน  $1$  ไมโครกรัมต่อลิตร

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KEYWORDS: MERCURY CONTAMINATION / SOIL / SHALLOW GROUNDWATER / DRINKING WATER / RIVER WATER / GOLD EXTRACTION / AGRICULTURE / PHYSICOCHEMICAL PROPERTIES

DONI MARISI SINAGA: ENVIRONMENTAL IMPACTS OF MERCURY ON SOILS AND WATER RESOURCES IN SEKOTONG'S GOLD MINING VILLAGE IN LOMBOK ISLAND, INDONESIA. ADVISOR: ASSOC. PROF. WATTASIT SIRIWONG, Ph.D., CO-ADVISOR: PROF. MARK G. ROBSON, Ph.D., 117 pp.

The update levels of mercury concentrations and other physicochemical properties in soil and water resources (shallow groundwater and river water) during rainy season in December 2014 were measured for two Sekotong's gold mining villages in Lombok, Indonesia, named Tembowong (TE) and Gawah Pudak (GP) villages. The data revealed gold extracting processes involved at residential areas burden soil, groundwater, and river water with mercury. Mercury concentrations (mean  $\pm$  SE) in groundwater at TE village (n=7) and GP village (n=7) were  $0.081 \pm 0.017$  ug/L and  $0.407 \pm 0.328$  ug/L, respectively. In average ( $\pm$  SE), mercury concentrations in soils (n=7) were found at  $0.392 \pm 0.170$  mg/kg in GP village and at  $0.265 \pm 0.160$  mg/kg in TE village. Active cyanidation (n=1) contributed mercury concentration on soils (0.522 mg/kg) and groundwater (0.170 ug/L) which is higher than amalgamation which was found in soils and groundwater at site with amalgamation facility (n=8) were found respectively at  $0.139 \pm 0.075$  mg/kg and  $0.064 \pm 0.009$  ug/L. At sites with a combination of active amalgamation and cyanidation, mercury concentrations (n=1) increased on the 1.175 mg/kg on soils and 1.268 ug/L in groundwater. The groundwater in GP and TE village contained high % saline (mean  $\pm$  SE)  $1.09 \pm 0.43$ . The mean level ( $\pm$  SE) of groundwater dissolved oxygen (DO) at the villages was  $1.72 \pm 0.35$  mg/L. The result shows the groundwater oxidation-reduction potential (ORP) was less than 650 mV. Soils in both villages (pH, 6.40–9.19) were more alkaline than the groundwater (pH, 5.80–8.00). The soils in GP village were found more alkaline, humidity, salinity, ORP, and had higher mercury than found in TE village; however there was a significant difference only in the ORP ( $p < 0.01$ ). At residences which also used as agricultural field (n=6), the mean level ( $\pm$  SE) of mercury was measured at  $0.447 \pm 0.385$  ug/L in groundwater and at  $0.455 \pm 0.198$  mg/kg in soils. Soil moisturizer was the only parameter associated positively to mercury concentrations of soils ( $r_s=0.798$ ). Besides, mercury concentrations (n=1) at the estuary zone were 1.764 ug/L, above the standard by US.EPA ( $< 1$  ppb).

Field of Study: Environmental Management  
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## CHAPTER 1. INTRODUCTION

### 1.1. Theoretical Background

Mercury contamination in environment is a major concern because of its toxicity and bio-accumulative ability. Mercury can be mobilized from sediment if the physicochemical properties change and transferred through aquatic food webs to fish, piscivorous animals, and humans [1]. The maximum level of mercury and the exposure effect on human, animal, and in vitro system have also been assessed massively [2]. A review by Zahir *et. al.* [3] shows effects of mercury to human respiratory system, reproduction, nervous system and early life neuro development in relatively low exposures. In Wanshan mercury mining area, China, high urine Hg was found in the residents lived within 3 km to the mine waste tailing and it may cause impairment of renal function [4].

In Sekotong's villages, in Lombok, Indonesia, artisanal and small-scale gold mining (ASGM) operations have been started since 2008 with inappropriate management to the heavy metal-containing waste [5]. Anderson [6] found in Sekotong, extracting gold includes a two-stage process of amalgamation and cyanidation can be recognized as mercury contamination resources. Moreover, the residence has been used for agriculture that might change soil characteristic and contribute to mercury contamination from soil to groundwater.

Physicochemical properties determine mercury mobilization from sediment and soil to water resources and transferred through aquatic food webs to humans. Thus, the information of how physicochemical properties associated to the mercury transportation will lead to better prevention actions. This research is aim to provide the update level of total mercury (T-Hg) and other physicochemical properties, to represent the quality of soil and water resources, based on the human activities involved. We also try to show what activities significantly change the mercury concentrations and the physicochemical properties, and try to find the significant factors associated to mercury concentrations in soil and groundwater.

## 1.2. Objective

1. To provide the update levels of mercury concentrations in soil and water resources (shallow groundwater and river water)
2. To provide the update levels of physicochemical properties in soil and water resources (shallow groundwater and river water)
3. To find a relationship among mercury concentrations level and other physicochemical properties of soils and groundwater

### 1.3. Hypotheses

1. There is mercury contamination in soil, stream and well samples in the population living area resulting small-scale gold extraction operations.
2. There are a relationship among mercury level and other properties in soil to water samples.

### 1.4. Scope of the Study

In the two selected “gold mining” villages, Gawah Pudak and Tembowong village, in Sekotong regency, Lombok Island, Indonesia, the improper handling of mercury tailing has been noticed. This research is aimed to evaluate the mercury (Hg) contamination and the physicochemical properties in soil and water resources in the population living area resulting small-scale gold extraction operations, and also to determine what causes change in those subjected parameters.

## CHAPTER 2. LITERATURE REVIEW

### 2.1. Mercury contamination affected by small-scale gold mining

Mining is an intrusive activity and raises environmental concerns then this activity takes part in ecosystem, and compromises human health through food chain or by contaminating drinking water resources. Contamination of the environment with heavy metals is a major concern because of their toxicity and bio-accumulative ability. Heavy metals can be mobilized from sediment if the physicochemical properties change [1] and are transferred through aquatic food webs to fish, piscivorous animals, and humans. Generally, low concentration of Rare Earth Elements (REEs) is present in soil, plant, water, and atmosphere; however, REEs can accumulate in such environments following anthropogenic inputs, because of the low mobility of these elements [7-9].

Mercury from an active gold mining area and also its mineralising processing affects to livestock health, and compromises the safety of derived food products. Gold mining is the major sources of mercury (Hg) contamination, especially in developing countries. Amalgamation is a simple process to extract gold by using mercury that potentially very dangerous and contaminated the air, soil, river, and lakes. Velásquez-López *et. al.* [10] found in many countries, such as Brazil, Colombia, Ecuador, Indonesia, Venezuela and Zimbabwe, amalgamated tailings are leached with cyanide to recover remaining gold.

## 2.2. The possibility of mercury contaminated in soil and water resources

### 2.2.1 Artisanal and small-scale mining (ASGM) operations

Artisanal and small-scale mining (ASGM) operations started in Lombok in 2008 and it has been continuing rise as the result of financial and employment reason. Anderson [6] noted the primary ore will be collected from visually identified sources by the hard-rock miners then the ore will be sold village-based process operators. However, in next 3 years, the economy and the resident's welfare have significantly improved, and as the result almost every household has their own ball-mills unit, located at their backyard [11]

Anderson [6] found in Sekotong, the miners recover gold through a two-stage process of amalgamation and cyanidation without any waste management, and the highest mercury waste is discharged to amalgamation tailings, after processed on the ball-mills, reached to 3,000 mg/kg of gold. A preliminary investigation showed every household has their own milling and amalgamation tailing which installed near the shallow groundwater well, the only drinking water resources in both selected study areas. A previous study by Prasetya *et. al.* [12] showed the mercury-containing waste resulted by cyanidation facility reached to 1,090 mg Hg per kg of gold.

Since the extraction process requires large volumes of water and resulting in deposition of mercury into any water body, many researchers take consideration

to the contamination settle in sediment, and its movement from water to soil then moving to food chain. Male *et. al.* [13] who worked on artisanal gold mining in Indonesia found the proportionately high level of total mercury in waste ponds; and as found in many places in developing countries, the researchers noticed the contaminated water was considered for watering agricultural lands. Moreover, Ning *et. al.* [14] discussed the high level of mercury, above the III class of National Surface Water Quality Standard, polluted the surface water of gold mining area in Linglong, China. The highest concentration of pollutant found in the points where the waste discharge and will decrease rapidly along with the distance far from the sources. The researchers found the concentration and distribution of heavy metal pollutants in surface water are dominated by the geochemical situation and the pollution source, and it becomes more serious by leachate and chemical wastewater discharge resulted by inappropriate management of small-scale gold mining activity.

### 2.2.2 Fertilizers used in agriculture

The two subjected gold mining areas are used not only for residence, but also for agriculture. The use of phosphate rocks as ingredient in chemical fertilizers and the accumulation of mercury in organic substance used in manufactured resulted make chemical and organic fertilizers as mercury resources in agriculture soils and groundwater [15]. Chemical fertilizer is known as a potential of mercury resources.

Ten chemical fertilizers from the Chongqing market, China have been known as mercury resources and the mercury content reached to 5.1 mg/kg [16]. Mortvedt [17] found that the use of animal manures and sewage sludges to manufacture organic fertilizers resulted with mercury accumulation in agricultural soils.

### 2.3. Mercury level correlated to properties of water and soil and rainy season

The concentration of particulate Hg per unit particle weight is relatively constant reflecting perhaps sorption equilibrium between dissolved and particulate phases [18]. In intensively high cultivated chili fields, where the farmers used chemicals as the heavy metal resources, the concentration of heavy metals appeared higher during rainy season than dry season [19]. These results suggest that the heavy metals desorbed and leached from contaminated soil into groundwater [20]. Moreover, fractionation of selected heavy metals associated with their accumulation, migration and bioavailability in soil and the subsurface environment [21, 22]. The exchangeable fraction plays important role to the bounding forms of heavy metal in soil, including the adsorptive and exchangeable, and those bounds to carbonate, which are easily leached if the environmental conditions are changing, including pH and salinity.

#### 2.3.1 pH

The pH plays important role to the heavy metal concentrations in soil and will change the migration and the accumulation at the study areas. The water pH will be tended to show the alkaline pH during the rainy season. The higher pH,

during rainy season, combined with the oxidizing environment would tend more to release Arsenic into the groundwater [19, 23]. Buchhamer *et. al.* [20] suggest that Arsenic might be leached into water body by desorption process that are increase by alkaline condition. However, Xu *et. al.* [24] found the amount of Hg released from soil at different pH values varied where the least value was obtained at pH 3 and 9, while the high desorption process were observed at pH 5 and pH 11.

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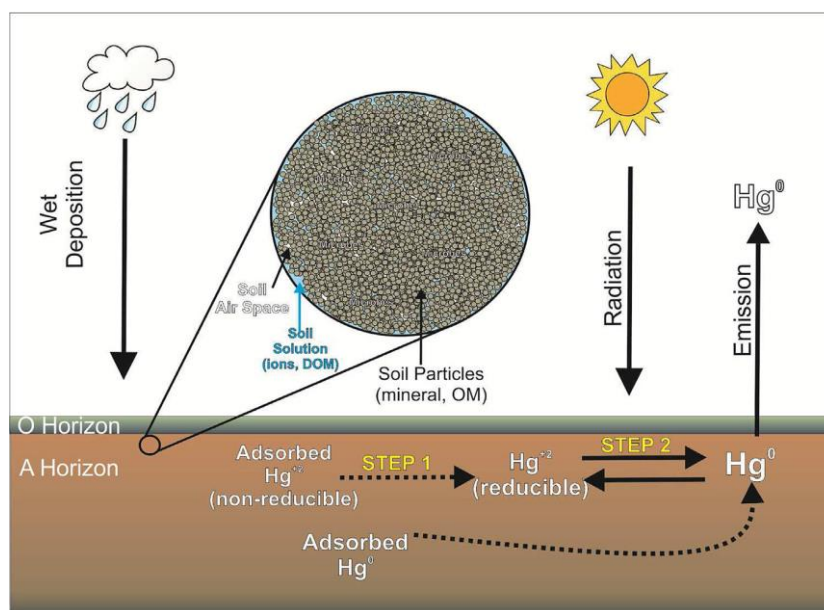


Figure 1 Schematic major process and factors affecting the reducible mercury formation (Step 1) and the production process of elemental mercury in next step (Step 2) (Figure adapted from [26])

The alkaline environment was not favorable for  $\text{Hg}^{2+}$  desorption, and thus, when the pH increase, the mercury tends to adsorb to soil particles, and decline the release of Hg from the soil to surrounding environment [27]. Contrary, Schluter [28] found the high repel force between soil particles and mercury forms from strongly alkaline soil treated with  $(\text{CH}_3)_2\text{Hg}$ , and the mercury evasion was found to be lowest for slightly acid soil. The  $\text{Hg}^{(+2)}$  desorbability, the tendency of Hg to release, increased at pH 7.0-9.0, and decreased at pH 3.0-5.0 [27]. The previous studies found the  $\text{Hg}^{2+}$  desorption, the trend of Hg to release on soil particles, occurs from pH 2 to 4, and adsorption maxima between 4 to 5 [29, 30]. These studies indicate the magnitude of  $\text{Hg}^{2+}$  varies with multiple mechanisms responsible for this behavior.

### 2.3.2 Temperature

Gustin and Stamenkovic [31] proved a synergism between soil moisture and light when the soils were not saturated well – the Hg emission from wet soils is greater when exposed by direct sunlight than shaded or in the dark. When water is exposed by solar irradiation, the energy converts to thermal energy, resulting with a rising water temperature, then promotes the Hg emission. Pannu *et. al.* [32] obtained the increase of temperature increases the logarithm of cumulative mass of Hg<sub>(0)</sub> and reduce the reduction rate constant, and as the result the percent of total Hg reduced will increase. This exposure also facilitates the increasing of vapor pressure and the thermal motion of the Hg compounds then contributes to the desorption of Hg from substrate and enhances the activities of the bacteria that are responsible for the reduction of Hg species [9, 28]. As the result the high temperature will drive to a lower mercury contained in media.

Moreover, when Marumoto and Imai [33] studied dissolved gaseous mercury (DGM) in seawater of Minamata Bay, a significantly positive correlation was found between water temperatures and DGM. This report said the higher temperature measured in water, the higher Hg will be released and resulted with decreasing of Hg concentrations measured in water, even not significantly; however, the significant correlation was only shown in summer season at the more open sea sites.

### 2.3.3 Water content

Pannu *et. al.* [32] defined the increase of percent water filled pore space increase the logarithm of cumulative mass of Hg<sub>(0)</sub> and reduce the reduction rate constant, and as the result the percent of total Hg reduced will increase. The Hg concentration will be reduced after cycled to the Hg emission releases to atmosphere. Gustin and Stamenkovic [31] found that a level below the saturation delivers an immediate release of elemental Hg from soil surface to soil water and the water movement is followed with Hg desorbing from soil particles into soil gas and dissolved in the soil water; however, the researchers revealed a decreasing level of Hg emission when the soil moisture were only in saturation, and it resulted an high accumulated level of Hg in soil.

Briggs and Gustin [34] also discovered a suppressed Hg-emission when the soils were saturated. These studies support our result that shows a strong positive correlation between soil moisture and the ability of Hg to stick in soil particles. Hintelmann and Harris [35] concluded that the saturated condition between water and soil particles increase the Hg partitioning in soil particle sorption sites and resulted with increasing levels of Hg(II). Liang et al [36] found a significantly strong positive correlation was found between T-Hg when the land flooded, and also in this case the Hg flux of dissolved gaseous mercury (DGM) was found negatively correlated. It concluded that the more water contained in soil the more T-Hg retained.

#### 2.3.4 Oxidation Reduction Potential (ORP)

The reducing condition of soil or groundwater may reduce the T-Hg concentration by reducing Hg (II) to Hg (I) or Hg<sup>0</sup> and promoting the Hg methylation microbial process [37]. In this work, along the ranged of the observed ORP levels, an oxidizing condition of groundwater was not followed with the degradation of organic matter, as mentioned in Randall and Chattopadhyay [37]. Moreover, found by Marumoto and Imai [33] the water T-Hg concentration was negatively correlated, but not significant, to the measured ORP level.

#### 2.3.5 Electrical Conductivity

The electrical conductivity (EC) of the freshly obtained non-filtered water samples will be measured at the field using a EC meter. The EC value will be used to estimate the amount of dissolve minerals in water samples especially salts or conductive ionic species in soil, such as  $S^{2-}$  and  $Cl^{-}$  ions, which determines Hg speciation and adsorption to soil particles [38]. Pannu *et. al.* [26] showed only electrical conductivity (EC), one of the soil parameters, was a significant factor to predict how the Hg (0) cumulative was related to soil moisture in boreal soil.

Liang *et. al.* [36] revealed a significantly strong positive correlation between T-Hg and EC level in flooded soil. In this study, EC level may also represents indirectly the Hg<sup>2+</sup> concentration in water since EC level shows the cation and anion dissolved from the soil that may be resulted from Hg<sup>2+</sup>. In contrast, the

researchers also discovered a significantly negative correlation between EC level and Hg flux. This research concluded that soil capacity to retain mercury may increase positively with the EC level.

### 2.3.6 Organic Matter

The organic matter may either act as a sorbent or provide high concentrations of dissolved ligands that form very strong complexes to Hg (II), as reviewed by Randall and Chattopadhyay [37]. The sorption of Hg onto particles can be significantly affected by the presence of complex ligands in several possible formation processes that may also involve an association to metal, electrostatic repulsion, or even mineral [39]. The same trend was also found by Kozyatnyk *et al.* [40] where an association between mercury and high molecular weight fraction of groundwater dissolved organic matter was found and has been used to absorb the mercury as relatively strong DOM-complexes. Liang *et al.* [36] also revealed the more T-Hg found when more organic contained in the soil.

### 2.3.7 Salinity

Marumoto and Imai [33] revealed a significant negative correlation was found between the salinity and T-Hg concentration of seawater in coastal site, Marina Bay to the T-Hg concentrations. Rolfhus and Fitzgerald [41] suggested that to increase of labile Hg (II), driving to reducing the T-Hg concentrations in water and enhancing the Hg(0) production on sediment, the water salinity need to be higher

to promote the reduction of abundant Hg organic complexes. Salinity can also affect Hg complexation in seawater, likely in mercuric chloride forms, resulting with positive correlation between T-Hg concentrations and the salinity level [42, 43].



## CHAPTER 3. MATERIALS AND METHODS

### 3.1. Sampling area

The samples were expected to perform the mercury level in two selected 'gold mining' villages in Sekotong regency, which is Gawah Puduk village – GP (S 08° 45' 51. 1" and E 115° 56' 41. 7") and Tembong village – TE (S 08° 46' 04. 5" and E 115° 56' 39. 0"), shown in Fig.2. To cover the two subjected gold mining villages, a total of 42 shallow well water samples and 42 soil samples that collected nearby the well were measured to be the represent of 7 sampling locations and the 3 replications of each village. From each village, soil and well water samples were collected from 5 sites with small-scale gold extraction operation, and 2 sites without the extraction process to know the differences between area with and without amalgamation facility.

The mercury contamination in stream water was also assessed by collecting the water samples at Merebek river (S 08° 47' 00. 0" and E 115° 56' 58. 5"). The river cut the both villages, ended up to the sea, and was considered as disposal site of mercury-containing waste. A total of 18 river water samples was collected to represent 6 locations that cover the natural background site of the river (R1, TE village; R4, GP village), the sites which threatened by human activity (R2, TE village; R3, GP village; R5, the confluence), and the estuary site (R6). In total, the collected samples represent 20 sampling sites (GP1-7, TE1-7, and R1-6 from the river sites) as shown in Figure 2.

### 3.2. Sampling method

All samples were collected during the rainy season from two “gold mining” villages, during December 2014 in Sekotong Regency, Lombok Island, Indonesia. About 1557 mm of precipitation falls annually in Lombok, and in December the average of precipitation falls and temperature is 135 mm and 24.2°C, respectively [44].

The well water samples were drawn manually from the selected well by using a bucket while the river water samples were collected using a plastic 1.5 L jug. The bucket and the jug were acid washed at the site then were washed three times using the sampling water before sampling. A 50 mL water sample was poured into a Corning® 50 mL poly ethylene terephthalate (PET) Centrifuge Tube and then the sample was preserved with 0.4% HCl (v/v) in the field site and was stored in the insulated box with ice bags to avoid the transformation and adsorption of Hg [45].

Near the selected well, between well and tailing pond, soil samples were collected from a depth of 0-20 cm. Gloves were used during sample collection to prevent skin contact. All soil samples were immediately placed in doubled dark Zip-Lock plastic bags to avoid cross contamination, and the samples were stored in the insulated box with ice bags. To avoid contamination, single-use gloves were used when collected each sample. In the laboratory, all soil samples were air dried at room temperature and the large organic and inorganic debris were removed. Then, the soil



samples were grounded to < 100 mesh using an agitate mortar before next chemical analysis [45].

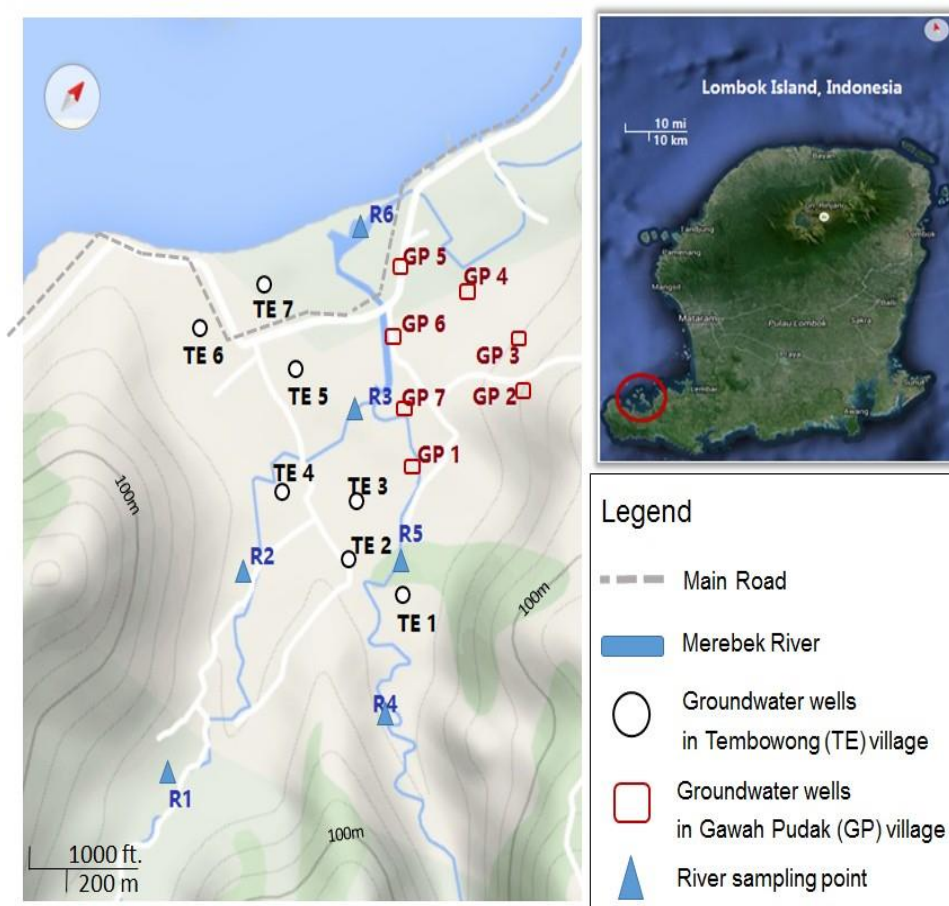


Figure 2. The sampling location represents the two selected ‘gold mining’ villages in Sekotong regency, Lombok. Well water and soil from both villages were collected from 14 locations (TE1-7 from Tembong village, and G1-7 from Gawah Puduk). Six sampling points were selected to obtain the stream water (R1-6)

### 3.3. Method validation

The concentrations of the mercury standard that used in metal calibration were 0.05, 0.1, 0.2, 0.4, 0.8, 1.6, and 3.2  $\mu\text{g/L}$  and were measured by Mercury Analyzer type VM-3000 with mercury vapor monitor. The correlation coefficient that obtained from

the linearity test for metal calibration in soil and water samples was 0.9992 and 0.9985, respectively. Regarding to the inter and intra-observer variation, the quality control (QC) was controlled following the SNI 06-6992.2-2004 method, accredited to IKU/5-4//MA-01 (for water samples) and IKU/ 5-4/MA-05 (for soil samples) by Laboratorium Penelitian dan Pengujian Terpadu (LPPT) – Universitas Gadjah Mada (UGM), Yogyakarta, Indonesia. The laboratory has been assessed and accredited by SNI ISO/IEC 17025:2005 to conduct calibration and analytical test. The limit of detection (LOD) and the limit of quantification (LOQ) calculated in 10 replications for soil samples were estimated  $1.02 \times 10^{-4}$  and  $3.41 \times 10^{-4}$  mg/kg, respectively, while measured in water samples were 0.03 and 0.10  $\mu\text{g/L}$ , respectively. The recovery of mercury concentration determination in soil (with 10 replications) and water samples (with 6 replications) was 73.28% and 103%.

#### 3.4. Digestion procedure

Digestion procedure was carried out according to Voegborlo and Akagi [46] and as modified by Eka *et. al.* [47]. For soil samples, an approximately of 5 g dry weight basics of each homogenized sample was accurately weighted into 100 mL Erlenmeyer flask and was added with 10 mL of the mixture of  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$  (4:1). The mixture was heated subsequently at a temperature between 100-110 °C until the solution be clear. The sample, then, was cooled and be diluted to 25 mL with distilled water. The digestion procedure for water follows the Standard National Indonesia (SNI)

6989.78:2011 related to the mercury determination in water [48, 49]. The 10 ml of water sample was added into 100 mL volumetric digestion flask and then the free-mercury water was added until the marker. The mixture solutions were added with a mixture of  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$  (3:1).

### 3.5. Mercury determination

Each sample was transferred into a reaction flask, and was added with 0.1 mL of Potassium permanganate 0.1 M and was shaken. To reduce the excessed permanganate remained after reaction, one tenth mL of hydroxylammonium chloride 10% (w/v) was added. Then, 0.5 mL of Tin (II) chloride 10% (w/v) in HCl 1 M was subsequently added to reduce mercury contained in the sample. The bottle then was connected to the reaction unit of the Lab Analyzer 254 then the samples were measured by Mercury Analyzer type VM-3000 with mercury vapor monitor. The mercury was quickly stripped from the reaction flask. The absorbance result was shown on the display after 60 - 80 second. The absorbance value was used for the calculation of analyses contents in the sample. All concentrations were reported in a wet weight basis.

### 3.6. Physicochemical property determination

The pH, electrical conductivity (EC), oxidation-reduction potential (ORP), dissolved oxygen (DO), and salinity of the freshly collected non-filtered samples were

measured in-situ using a pH/EC/ORP meter, respectively. For the soil samples, the pH and EC value were measured in 1:2 v/v soil–distilled H<sub>2</sub>O suspensions [24]. The temperature of water and soil samples were measured *in situ* by using thermometer. The water percentage of soil samples were measured after drying at oven (105°C) to a constant mass [water (%) by mass = (wet mass - dry mass / dry mass) x 100]. The organic content was measured by standard procedure using furnace (550°C).

### 3.7. Statistical Analysis

After determined the distribution of all collected data using Kolmogorov-Smirnov (with Lilliefors Correction Test) and Shapiro-Wilk Test, the parametric and nonparametric test were used to determine the significant difference of the observed parameters in all measured media collected in both villages and also to show the correlation between the two subjected parameters. Post hoc tests were applied to identify differences between two villages and the river nearby ( $p$  value < 0.05). The Spearman correlation was used to show the correlation among the properties. The Spearman correlation coefficient was interpreted as Cohen in 1977 [50].

## CHAPTER 4. RESULTS AND DISCUSSIONS

The quality of soils and water resources in the subjected areas represents the suitability for drinking, domestic, livestock and agricultural purposes. Shallow wells and river water are the water resources, and deserve to follow the standard set by US.EPA [51, 52] whilst the level of mercury and other physicochemical properties of soils was compared to the US.EPA for soil quality which also been used in several publications [53-55] . However, the soils and water resources are easily contaminated by mercury from the nearby gold extraction process, including amalgamation and cyanidation, and fertilizer uses in agricultural sectors. These activities may causes changes to mercury concentrations and the other physicochemical properties which used to represent the quality of soils and water resources in the study areas. The soil parameters are observed in this research to show the relation to the water resources.

### 4.1. Soil and groundwater properties at the two subjected Sekotong's gold mining villages

Fourteen sampling locations were selected to represent the two massive gold mining villages at Sekotong regency, Lombok Island, Indonesia, named Tembong (TE) and Gawah Pudak (GP) village. At each sampling location, groundwater samples were collected from a shallow well that used as drinking water resources and watering the agricultural field. Soil samples were collected near the subjected shallow well in order to measure the quality of soils and to

find the correlation between soil properties and groundwater properties. The properties of the observed soils and groundwater at two subjected villages and their compliances were shown at Table 1. By Mann-Whitney test, the  $p$  value less than 0.05 indicated a significant difference of each parameter of the matrices observed in Tembowong (TE) and Gawah Puduk (GP) village such as groundwater EC, ORP and DO, and also soil ORP. Appendix provides the detail of soil and water properties at each sampling location from the two subjected villages.

Table 1. Statistical comparison of soil and groundwater properties from Tembowong (TE, n = 7) and Gawah Puduk (GP, n = 7) village

Matrices	Unit	Safe Limit <sup>1,2</sup>	Village	Min.	Max.	Mean		95% CI		Median	Std. deviation	$p$ value
						Statistic	Std. error	Lower	Upper			
<b>Groundwater</b>												
Mercury concentrations	ug/L	2	TE	0.042	0.166	0.081	0.017	0.04	0.122	0.068	0.045	0.848
			GP	0.032	2.37	0.407	0.328	-0.394	1.209	0.07	0.867	
pH	-	6.5-8.5	TE	5.9	7.55	-	-	-	-	-	-	-
			GP	6.5	7.9	-	-	-	-	-	-	-
Temperature	°C	-	TE	28.75	29.7	29.26	0.13	28.95	29.58	29.25	0.34	0.749
			GP	28.8	29.7	29.19	0.12	28.89	29.48	29.3	0.32	
EC	µs/cm	564-5,870	TE	514.5	769.5	632.5	35.36	545.97	719.03	630	93.56	0.002**
			GP	835.5	2,440	1,291.36	226.26	737.72	1,844.99	932	598.62	
ORP	mV	650-700	TE	13.6	55.7	40.91	5.36	27.81	54.02	43.55	14.17	0.035*
			GP	6.71	36.9	25.13	4.03	15.27	34.99	26.5	10.67	
DO	mg/L	> 2.8	TE	1.33	2.82	2.13	0.2	1.64	2.62	2.19	0.53	0.018*
			GP	0.57	1.76	1.31	0.15	0.93	1.68	1.43	0.41	
Salinity	%	0.1	TE	0	2	0.96	0.27	0.3	1.62	1	0.71	0.599
			GP	0.5	2.5	1.21	0.31	0.47	1.96	1	0.81	
<b>Soils</b>												
Mercury concentrations	mg/L	1	TE	0.012	1.068	0.265	0.16	-0.126	0.656	0.028	0.423	0.225
			GP	0.022	1.283	0.392	0.17	-0.023	0.808	0.182	0.45	
pH	-	4.0-9.0	TE	7.38	7.93	-	-	-	-	-	-	-
			GP	6.5	9.12	-	-	-	-	-	-	-
EC	µs/cm	< 4,000	TE	127.75	879	324.13	96.68	87.55	560.7	244.15	255.8	0.110
			GP	181.4	1,312.05	531.99	139.88	189.72	874.27	378	370.09	
ORP	mV	-	TE	8.65	17.57	13.88	1.3	10.71	17.06	15.32	3.43	0.002**
			GP	-65.95	5.45	-32.92	9.16	-55.33	-10.51	-37.65	24.23	
Water percentage	%	-	TE	8.21	30.83	23.48	3.02	16.09	30.87	26.24	7.99	0.225
			GP	13.48	42.74	29.1	3.88	19.61	38.6	29.22	10.27	
OMC	%	-	TE	1.4	7.84	4.16	0.79	2.24	6.09	4.03	2.09	0.179
			GP	1.25	4.61	3.12	0.38	2.18	4.06	3.08	1.01	

\*.  $p$  value  $\leq$  0.05

\*\*..  $p$  value  $\leq$  0.05

<sup>1)</sup> The drinking water safe limit set by US.EPA compliance [50,51], <sup>2)</sup> The soil safe limit set by US.EPA [52-54]

#### 4.1.1 Mercury concentrations

All groundwater samples from 14 shallow wells at two Sekotong's gold mining villages were contaminated with mercury. In average, mercury concentrations in groundwater of GP village were slightly higher than the level in TE village, as shown in Figure 3. Mercury concentrations (mean  $\pm$  SE) in groundwater at TE village and GP village were  $0.081 \pm 0.017$  ug/L and  $0.407 \pm 0.328$  ug/L, respectively. The mercury level of groundwater at both villages was below the safe limit set by US.EPA standard (2 ug/L).

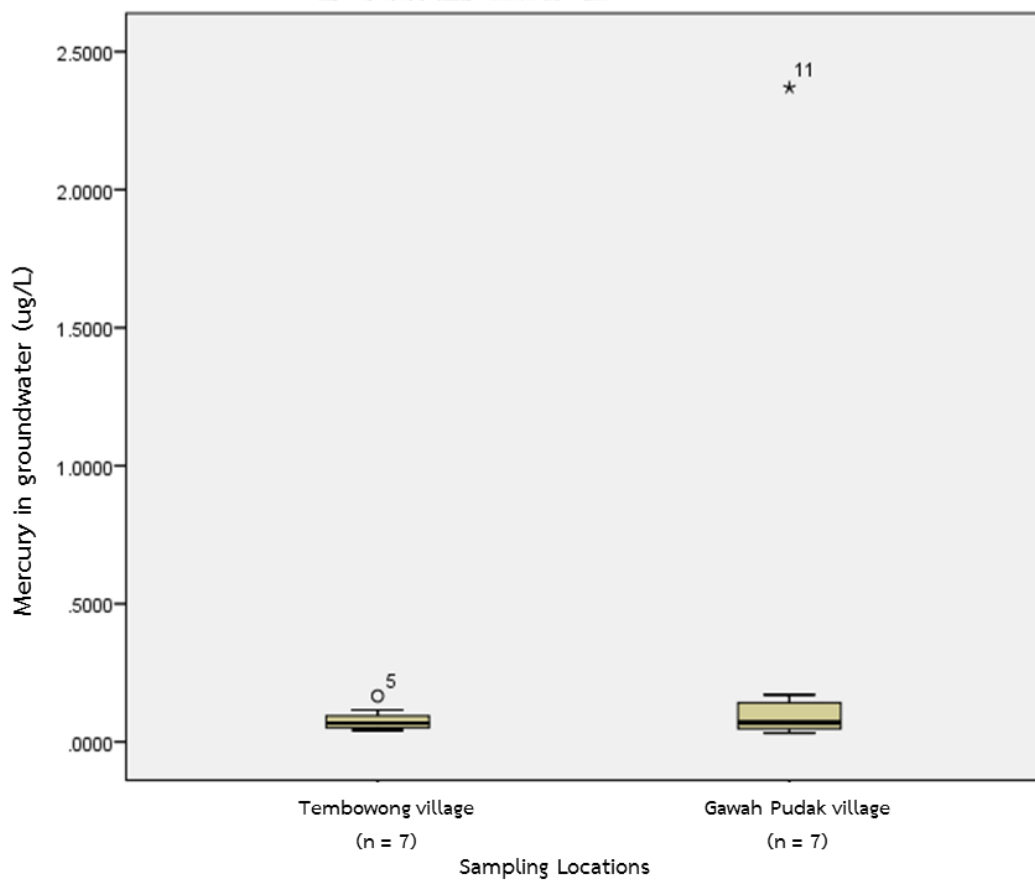


Figure 3. Mercury concentrations of groundwater in Tembong and Gawah Puduk village

The mercury concentrations of groundwater (mean  $\pm$  SE) at sampling location 4 in GP village (GP 4) were  $2,370 \pm 0.653$  ug/L whilst in other sampling points in this village the mercury levels ranged 0.032–0.170 ug/L. As comparison to GP village, no extreme value was found in 7 shallow wells in TE village, ranged 0.042–0.166 ug/L. Even though the pattern of mercury levels in both villages shows a slight difference, however after being analyzed by Mann-Whitney test, no significant difference of mercury levels of groundwater was found at those two villages.

Mercury was found in all soil samples both in TE village and GP village. In average, mercury concentrations in soils at GP village were slightly higher than the level at TE village, as shown in Figure 4. In average ( $\pm$  SE), mercury concentrations were found at  $0.392 \pm 0.170$  mg/kg in GP village and at  $0.265 \pm 0.160$  mg/kg. At each village, one sampling site was found above the compliance (US.EPA standard, 1 mg/ kg) at TE 5 ( $1.068 \pm 0.112$  mg/kg) and GP 4 ( $1.283 \pm 0.193$  mg/kg). No significant difference was found between the both villages in term of mercury concentrations of soils.



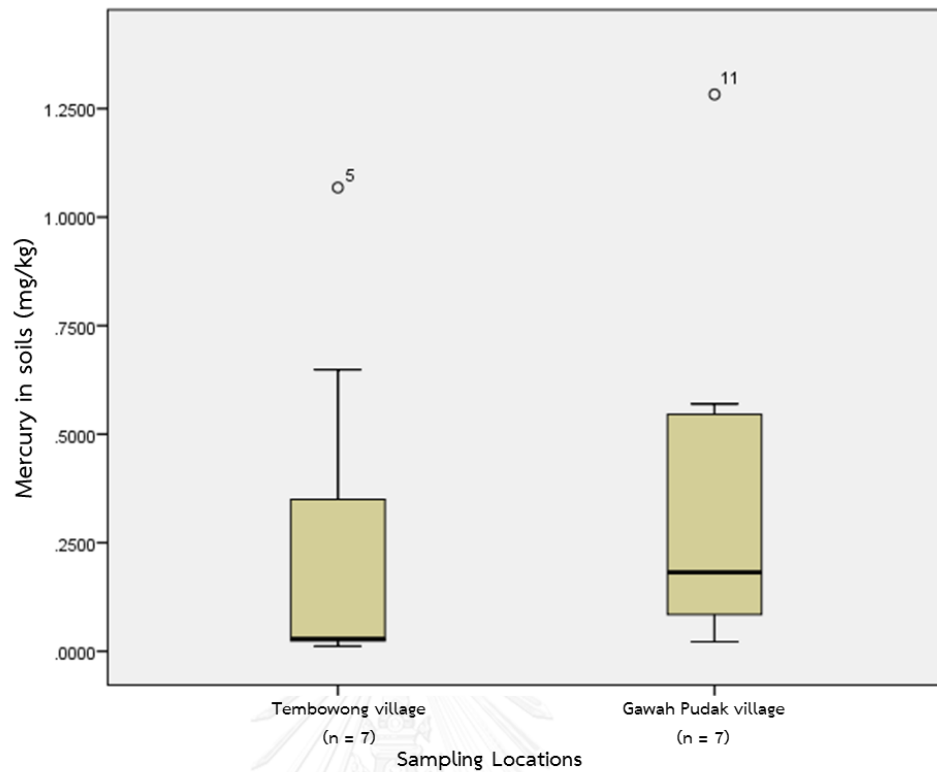


Figure 4. Mercury concentrations of soils in Tembong and Gawah Pudak village

#### 4.1.2 The pH

When the groundwater pH in both villages was compared (pH, 5.80–8.00), we found that the pH in out of 7 shallow wells in GP village, only one was found acidic (GP 7, 6.50), and the rest were neutral ranged 7.10–7.90. On the contrary, in TE village, only one was found neutral (TE 1, 7.55), and the rest were acidic ranged 5.90–6.50. Nevertheless, all shallow groundwater samples were under the US.EPA standard for drinking water (6.5–8.5) and were the normal pH of groundwater.

Soils in both villages were found at ranged 6.40–9.19. The same trend was also found for soil pH – GP village had higher soil pH than the level in TE village, soil pH in those gold mining villages was not significantly different. In general, soils

collected in GP village during the rain episodes were nearly neutral, with pH values ranging from nearly neutral (GP 2, 6.50) to a basic (GP 5, 9.12). The pH of soils collected nearby the observed wells at TE village was neutral only from a low of 7.38 in TE 7 and a high of 7.93 in TE 2. The groundwater pH in GP village was measured as a low of 6.5 and a high of 7.9 whilst the groundwater pH in TE village ranged from 5.9 to 7.55. The results show the soils are acceptable for agricultural purpose (pH, 4.0-9.0).

#### 4.1.3 Electrical conductivity (EC) and salinity

A significant difference was found when observed the electrical conductivity of groundwater between two observed gold mining villages ( $p$  value = 0.002). The electrical conductivity of groundwater in GP village was higher than the level in TE village, as shown in Figure 5. In average ( $\pm$ SE), the electrical conductivity of groundwater in GP village was counted at  $1,291.36 \pm 226.26 \mu\text{s/cm}$  whilst in TE village was measured at  $632.5 \pm 35.36 \mu\text{s/cm}$ . It indicated that the EC of groundwater samples collected from the shallow wells at TE and GP villages was under the safe limit of 564-5,870  $\mu\text{s/cm}$ , set by US.EPA. However, among seven shallow wells in GP village, one was found moderately saline (GP 4,  $2,440 \pm 0 \mu\text{s/cm}$ ) whilst others were found slightly saline, range from 835.50 to 1,701  $\mu\text{s/cm}$ . In TE village, five of seven shallow wells were found non-saline (TE1, TE 3, TE 4, TE 5, and TE 6) whilst TE 2 and TE 7 were slightly saline.

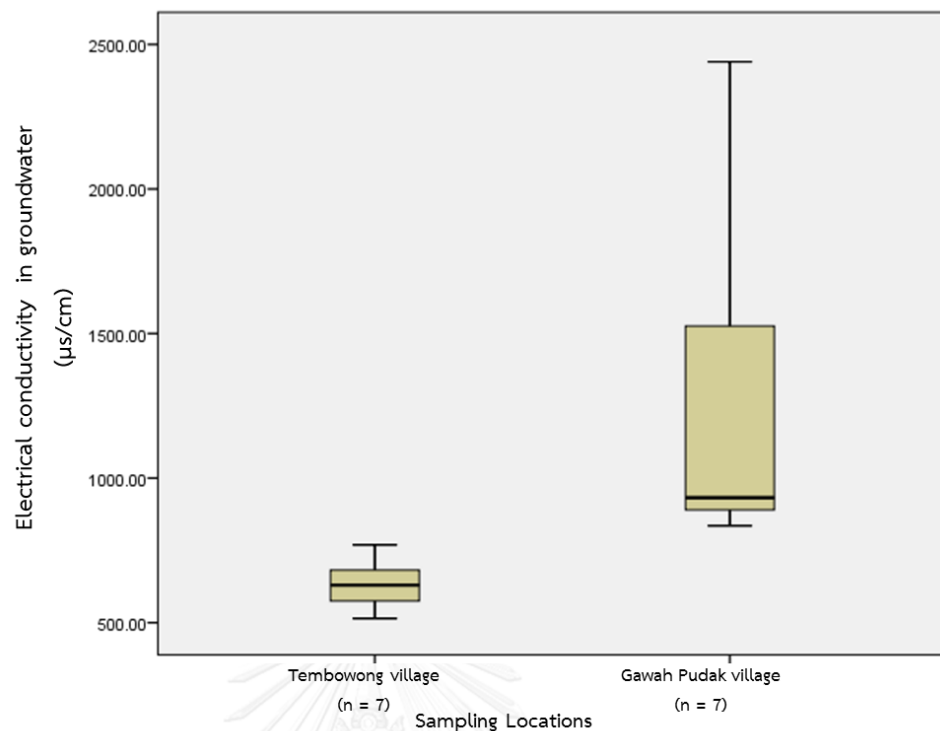


Figure 5. Electrical conductivity of groundwater in Tembong and Gawah Pudak village

The EC level is always measured to represent the salinity level. The groundwater in GP and TE village contained high % saline (mean  $\pm$  SE)  $1.09 \pm 0.43\%$ . Similar to the pattern of the EC level, the salinity of groundwater in GP village was higher than the levels in TE village, but was not statistically significant, as shown in Figure 6. The salinity in GP village and TE village was  $0.121 \pm 0.03\%$  and  $0.10\% \pm 0.03\%$ , respectively. Salt concentration above safe limit, set by US. EPA (0.1%), was found in GP village (GP 1, GP 4, GP 5, and GP 6) and in TE village (TE 3, TE 4, TE 5, TE 7). The highest salinity of both villages was found in TE 3 and GP 4 at 0.2% and 0.25%, respectively. The groundwater of both villages can be

categorized as brackish water or briny water regarding to the saline level of ~ 5 g/L [56].

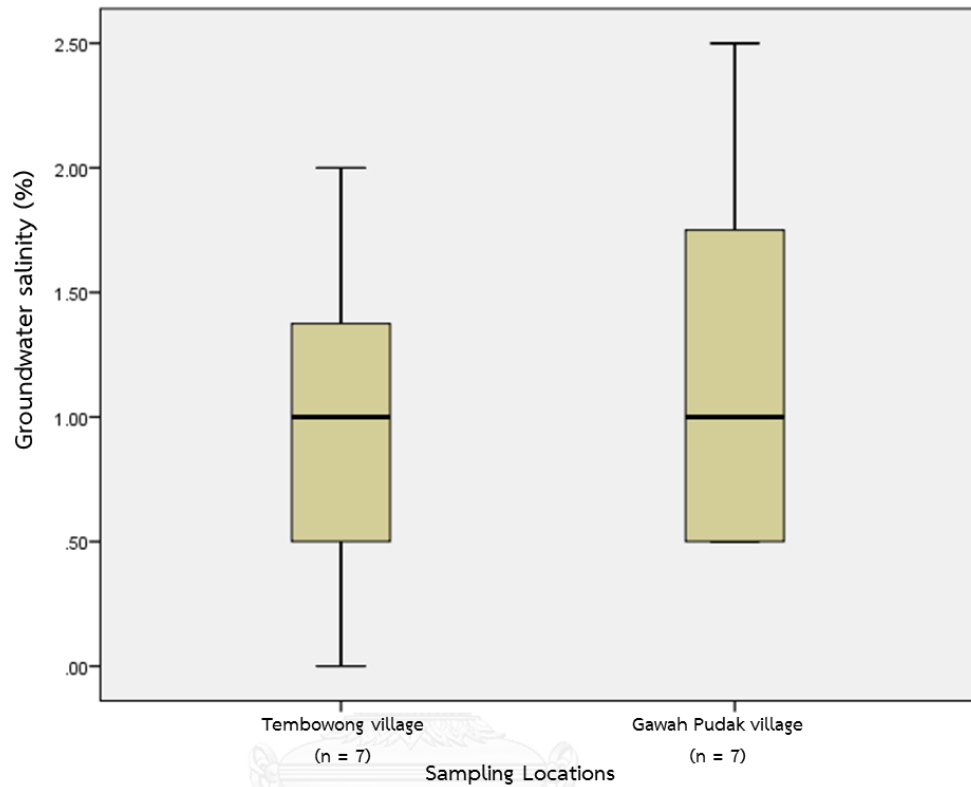


Figure 6. Groundwater salinity in Tembong and Gawah Pudak village

Soils in GP village had higher concentrations of EC relatively to the samples from TE village, as shown in Figure 7; however, in general, the soils in both villages were categorized as non-saline soils. The mean ( $\pm$  SE) of EC level found in soils at GP village and TE village was  $531.99 \pm 139.88 \mu\text{s/cm}$  and  $324.13 \pm 96.68 \mu\text{s/cm}$ , respectively. In detail, only one sampling site of both villages was found slightly saline ( $\text{EC} > 700 \mu\text{s/cm}$ ) at TE 3 ( $879 \mu\text{s/cm}$ ) and GP 4 ( $1,312.05 \mu\text{s/cm}$ ), but under the compliance for agricultural purpose (US.EPA,  $\text{EC} < 4,000 \mu\text{s/cm}$ ).

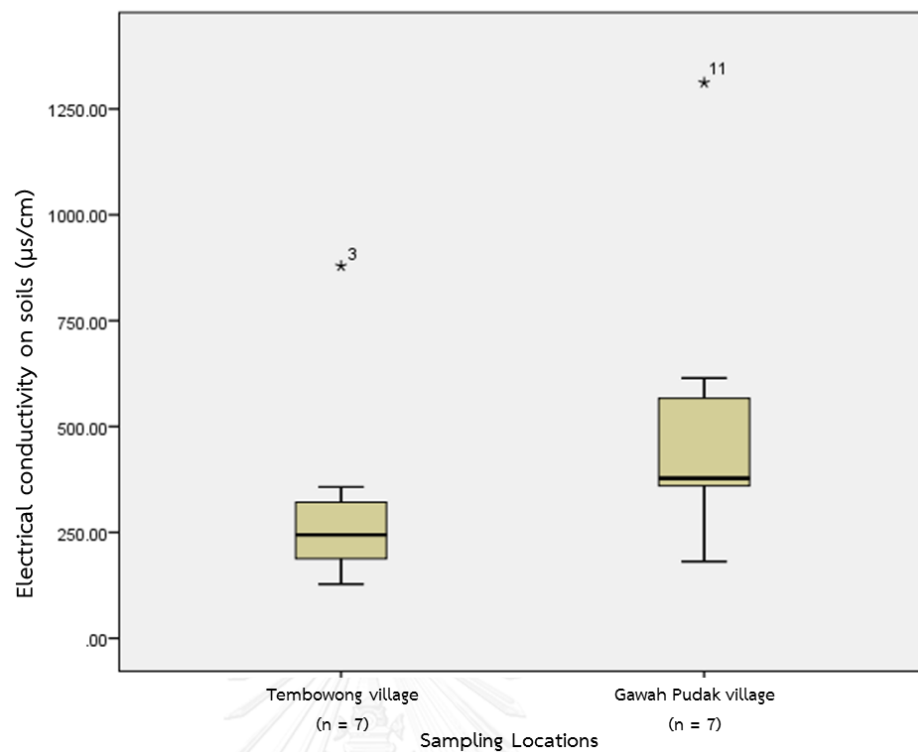


Figure 7. Electrical conductivity of soils in Tembowong and Gawah Pudak village

#### 4.1.4 Oxidation-reduction potential (ORP)

Unlike the EC pattern, the ORP of groundwater in GP village was significantly lower than the levels in TE village, as shown in Figure 8. The ORP level (mean  $\pm$  SE) in GP village was found at  $25.13 \pm 4.03$  mV whilst in TE village was measured at  $40.91 \pm 5.36$  mV. The ORP levels of all groundwater samples were found in moderate reducing condition. The maximum value of ORP in GP village was found in GP 6 with 36.90 mV and the lowest was found in GP 2 with 6.71 mV. In TE village, the highest ORP was found in TE 6 (55.70 mV) and the lowest was found in TE 1 (13.60 mV). The results of ORP measurement was below the compliance

650-700 mV and it indicated water hygiene is an issue at those subjected gold mining villages.

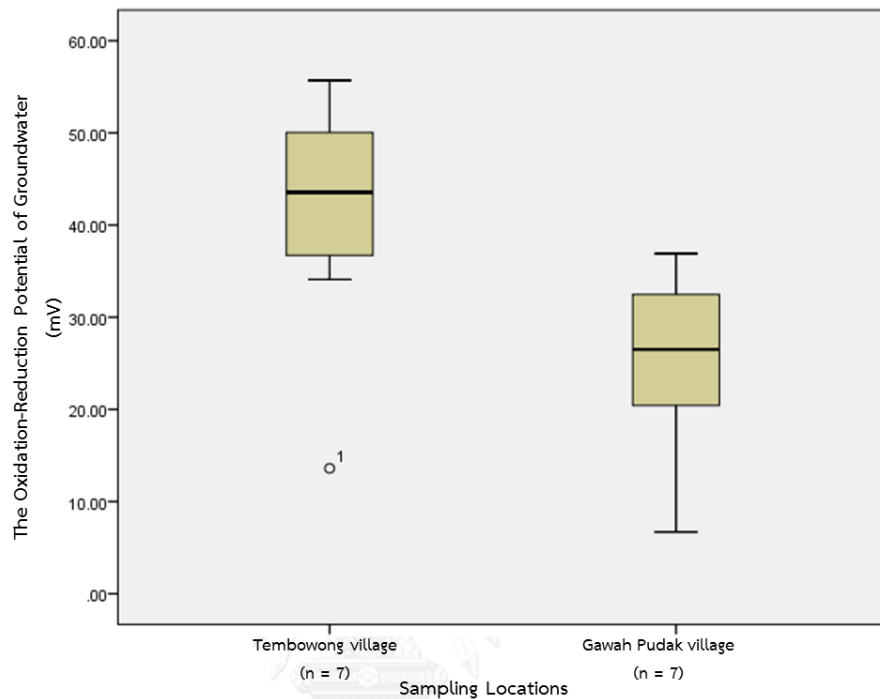


Figure 8. Oxidation-reduction potential of groundwater in Tembong and Gawah Puduk village

Perhaps unsurprisingly, the pattern of soil ORP was found differently with the soil EC. Soil ORP was found significantly higher in TE village than in GP village ( $p$  value = 0.002), as shown in Figure 9. Soils in TE village exhibited on oxidizing condition at  $13.88 \pm 1.30$  mV whilst a negative ORP reading in soils in GP village ( $-32.92 \pm 9.16$  mV) indicated that the soils were on reducing states. In TE village, sampling point 2 and 6 were found more oxidizing at 17.57 mV and 17.15 mV, respectively. The more anti-oxidizing state was shown in GP 5 ( $-65.95$  mV) and GP 4 ( $-50.6$  mV).

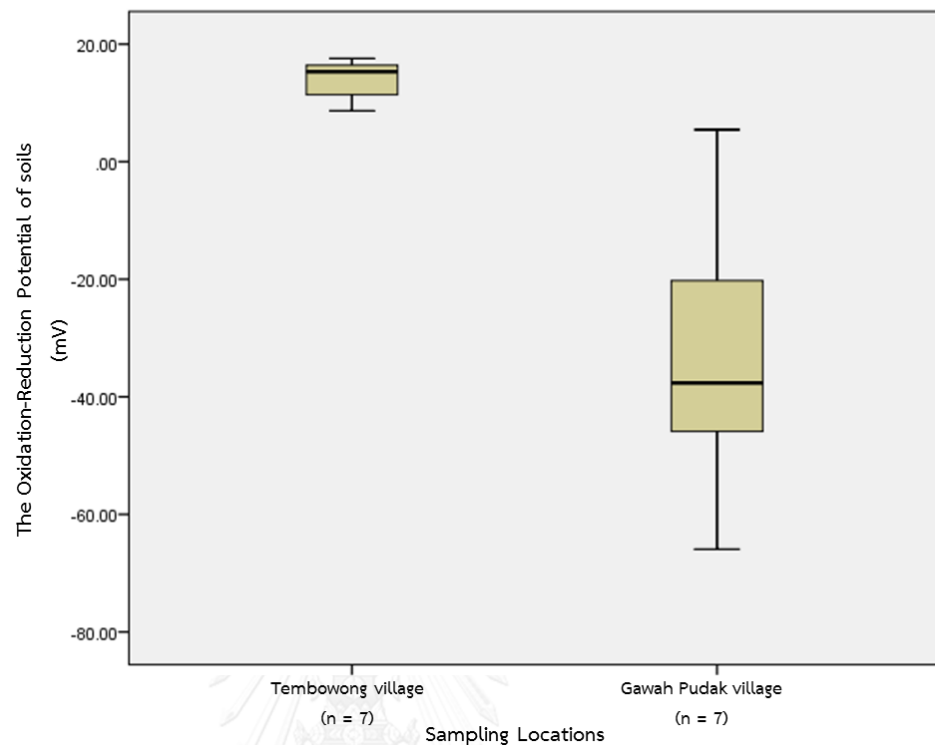


Figure 9. Oxidation-reduction potential of soils in Tembong and Gawah Pudak village

#### 4.1.5 Dissolved oxygen (DO) of groundwater

The mean level ( $\pm$  SE) of groundwater dissolved oxygen (DO) at the villages was  $1.72 \pm 0.35$  mg/L. As well as the ORP levels, the DO levels of groundwater in GP village was significantly lower than the levels in TE village ( $p$  value = 0.018, Mann-Whitney test), as shown in Figure 10. The DO levels in GP villages were varied from a low of 0.57 mg/L to a high of 1.76 mg/L with an average of 1.31 mg/L. In the TE village, the DO levels ranged from 1.33 to 2.82 with mean value 2.13 mg/L. The low level of DO may indicate excessive microorganism growth and the high

level of chemical demand. The mercury contamination, agricultural activity, and household waste may drive to a low DO level. de Jong *et. al.* [57] also found the mining and agriculture triggered a decrease of DO of groundwater.

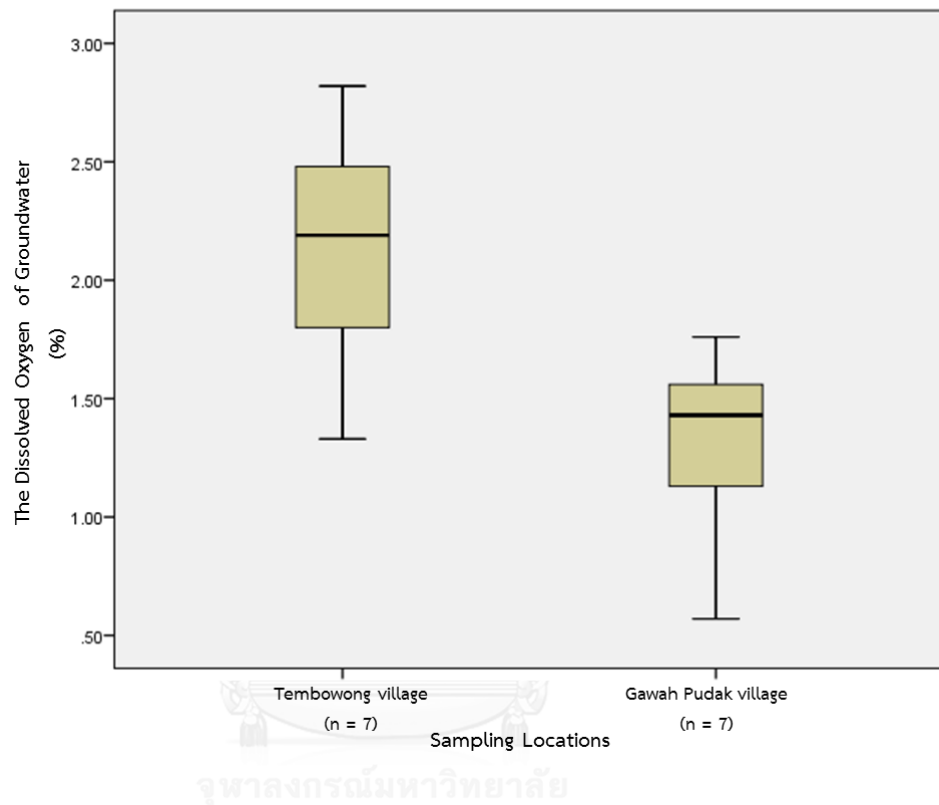


Figure 10. Dissolved oxygen of groundwater in Tembong and Gawah Pudak village

#### 4.1.6 Groundwater temperature

In terms of groundwater temperature, no significant difference was found between the wells in GP village and TE village, as shown in Figure 11. In average ( $\pm$ SE), the groundwater temperature in GP village was  $29.19^{\circ}\text{C}$  ( $\pm 0.12^{\circ}\text{C}$ ) and in TE village was  $29.26^{\circ}\text{C}$  ( $\pm 0.13^{\circ}\text{C}$ ). The observation in the seven sampling locations in



both villages shows a slight variation in temperature. In GP village, the minimum temperature was found in GP 5 (28.80) and the maximum temperature was found in GP 1 (29.70°C) In TE village, the lowest temperature was found in TE 7 at average of 28.70°C and the highest temperature was found evenly at 29.70°C in TE 6.

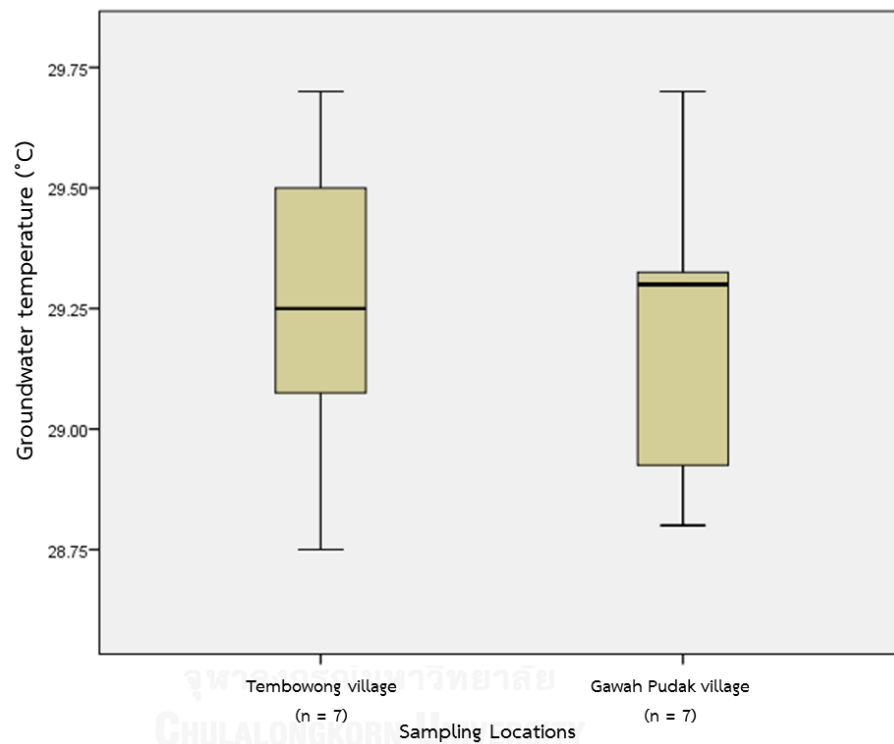


Figure 11. Groundwater temperature in Tembong and Gawah Pudak village

#### 4.1.7 Water percentage and organic carbon matter on soils

The soils at GP village's site were found relatively more moisture than the soils at TE village's site, as shown in Figure 12. During rainy season, the water content of soils measured in study areas was  $29.10 \pm 3.88\%$  (mean  $\pm$  SE) at GP site and  $23.48 \pm 3.02\%$  at TE site. In GP village, the water percentage of soils varied

from 13.48% at GP 7 to 42.74% at GP 4. Variations in soil moisturizer in TE village ranged from 8.21% at TE 1 to 17.57% at TE 2.

Contrast to water percentage, soils in TE village relatively contained more organic carbon matter than soils in GP village, as shown in Figure 13. Organic carbon in TE village and GP village was measured at  $4.16 \pm 0.79\%$  and  $3.12 \pm 0.38\%$ , respectively. Overall, the organic content was found varied in both monitoring sites ranged from 1.40% (TE 1) to 7.84% (TE 3) in TE sites and ranged from 1.25% (GP 7) and 3.74% (GP4) in GP sites.

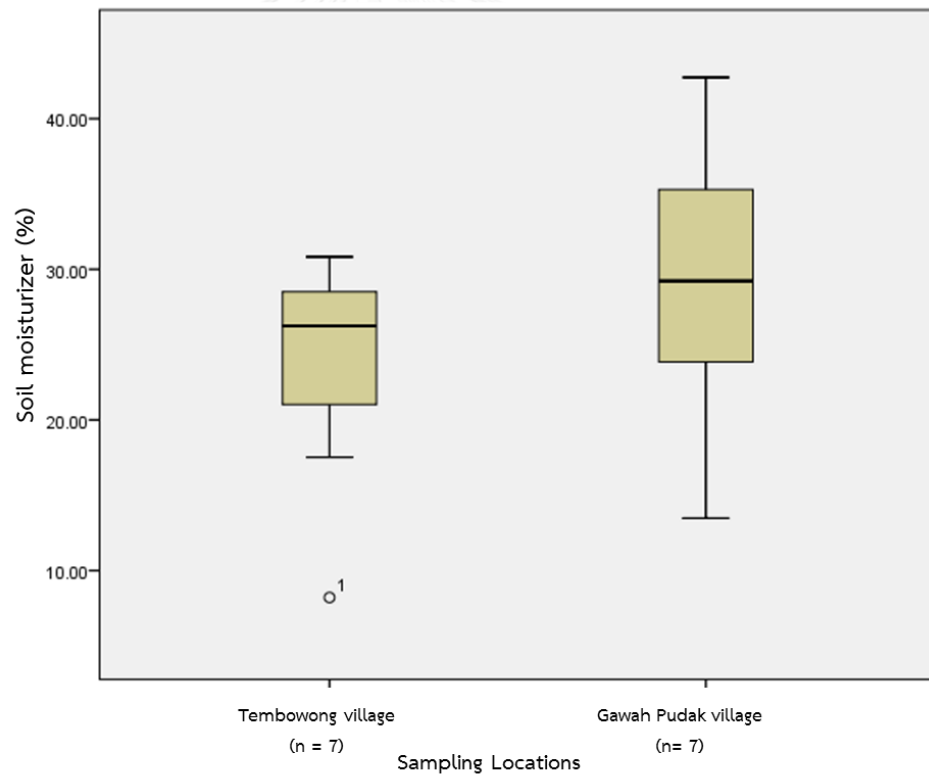


Figure 12. Soil moisturizer in Tembong and Gawah Puduk village

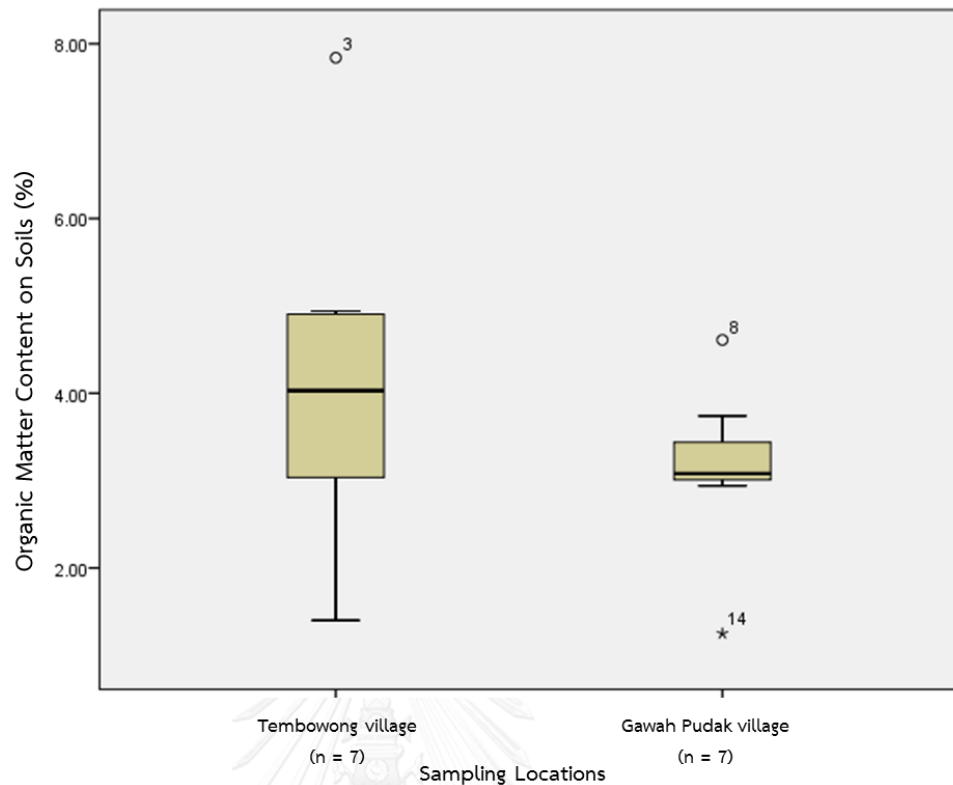


Figure 13. Organic matter content on soils in Tembawang and Gawah Pudak village

#### 4.2. Contribution of agriculture and residence to soil and groundwater properties

At the two subjected Sekotong's gold mining villages the land uses for residence with or without agricultural activity. Additionally, six of 14 monitoring wells were constructed in cultivated rice where corn, rice, long bean, peanut, and various types of tubers have been the main crops. Table 2 presents the quality changes of soils and groundwater in Sekotong's gold mining villages at residential area which used for agricultural purpose. The Mann-Whitney test indicated between the residence areas and the agricultural sites for all observed parameters the statistically significant difference ( $p < 0.05$ ) only exhibited for soil moisturizer.

Table 2. Statistical comparison of soil and groundwater properties at residence (n = 8) and agriculture (n = 6)

Matrices	Unit	Safe Limit <sup>1,2</sup>	Living Area	Min.	Max.	Mean		95% CI		Median	Std. deviation	P value
						Statistic	Std. error	Lower	Upper			
<b>Groundwater</b>												
Mercury concentrations	ug/L	2	Agriculture	0.032	2.370	0.447	0.385	0.542	1.436	0.059	0.942	0.651
			Residence	0.032	0.170	0.092	0.019	0.048	0.136	0.071	0.053	
pH	-	6.5-8.5	Agriculture	5.90	7.25	-	-	-	-	-	-	-
			Residence	6.05	7.90	-	-	-	-	-	-	-
Temperature	°C	-	Agriculture	28.75	29.70	29.29	0.15	28.91	29.68	29.33	0.37	0.560
			Residence	28.80	29.70	29.18	0.10	28.93	29.42	29.18	0.29	
EC	µs/c	564-5,870	Agriculture	522.50	2,440.00	1,093.75	293.20	340.05	1,847.45	802.50	718.19	0.699
			Residence	514.50	1,701.00	863.06	130.96	553.38	1,172.74	799.50	370.42	
ORP	mV	650-700	Agriculture	6.71	55.70	36.05	6.77	18.66	53.45	36.35	16.57	0.439
			Residence	13.60	53.00	30.75	4.80	19.40	42.10	27.83	13.57	
DO	mg/L	> 2.8	Agriculture	0.57	2.51	1.63	0.28	0.92	2.33	1.53	0.68	0.796
			Residence	1.04	2.82	1.79	0.22	1.27	2.30	1.71	0.62	
Salinity	%	0.1	Agriculture	0.5	2.5	1.46	0.33	0.61	2.31	1.63	0.81	0.163
			Residence	0	2	0.81	0.21	0.32	1.31	0.75	0.59	
<b>Soils</b>												
Mercury concentrations	mg/L	1	Agriculture	0.020	1.283	0.455	0.198	-0.055	0.965	0.376	0.486	0.302
			Residence	0.012	1.068	0.234	0.133	-0.081	0.549	0.057	0.377	
pH	-	4.0-9.0	Agriculture	6.50	8.55	-	-	-	-	-	-	-
			Residence	7.15	9.12	-	-	-	-	-	-	-
EC	µs/c	< 4,000	Agriculture	181.40	1312.05	545.68	184.40	71.67	1019.69	328.75	451.68	0.606
			Residence	127.75	614.50	339.84	59.80	198.43	481.25	352.00	169.15	
ORP	mV	-	Agriculture	-50.60	17.15	-10.01	12.04	-40.96	20.93	-0.38	29.49	0.796
			Residence	-65.95	17.57	-9.15	11.11	-35.42	17.12	8.00	31.42	
Water percentage	%	-	Agriculture	24.52	42.74	32.72	2.76	25.61	39.83	31.52	6.77	0.028*
			Residence	8.21	29.38	21.47	2.88	14.67	28.27	22.51	8.14	
OMC	%	-	Agriculture	2.94	7.84	4.40	0.75	2.47	6.32	3.79	1.83	0.272
			Residence	1.25	4.87	3.08	0.49	1.92	4.23	3.11	1.38	

\*. p value ≤ 0.05

1) The drinking water safe limit set by US.EPA compliance [50.51], <sup>2)</sup> The soil safe limit set by US.EPA [52-54]

#### 4.2.1 Mercury concentrations

Compared to the groundwater in residence area, the mean ( $\pm$ SE) level of T-Hg was found 4.85 times higher in agricultural site ( $0.447 \pm 0.385$  ug/L), ranged 0.032–2.370 ug/L), as shown in Figure 14. The same trend also found in the soil whereas the mean level of T-Hg was found 1.95 times higher in agricultural fields ( $0.455 \pm 0.234$  mg/kg, ranged 0.020–1.283 mg/kg), as shown in Figure 15. Measured on residence, the soil and groundwater samples were measured with mercury at the mean level ( $\pm$  SE) of  $0.234 \pm 0.133$  mg/kg and  $0.092 \pm 0.019$  ug/L, respectively. In residential site, mercury concentrations of soils ranged 0.012–1.068 mg/kg whilst vary measured in groundwater from 0.032 ug/L to 0.170 ug/L.

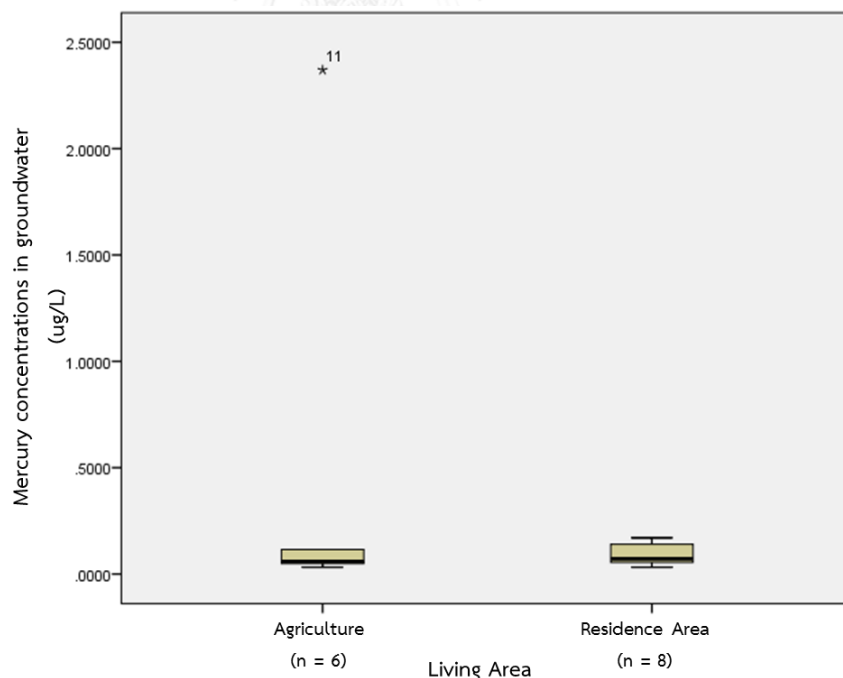


Figure 14. Mercury concentrations in groundwater in agriculture and residence area

In average, the mercury contamination on soils and groundwater was below the compliance. No significant contribution of agriculture to mercury contamination, however the results show the high mercury contamination can be found at site with agricultural activity. It indicated the mercury contamination may be not directly related to the agricultural activity, but the increasing of mercury levels on soils and groundwater can be impacted by agricultural activity.

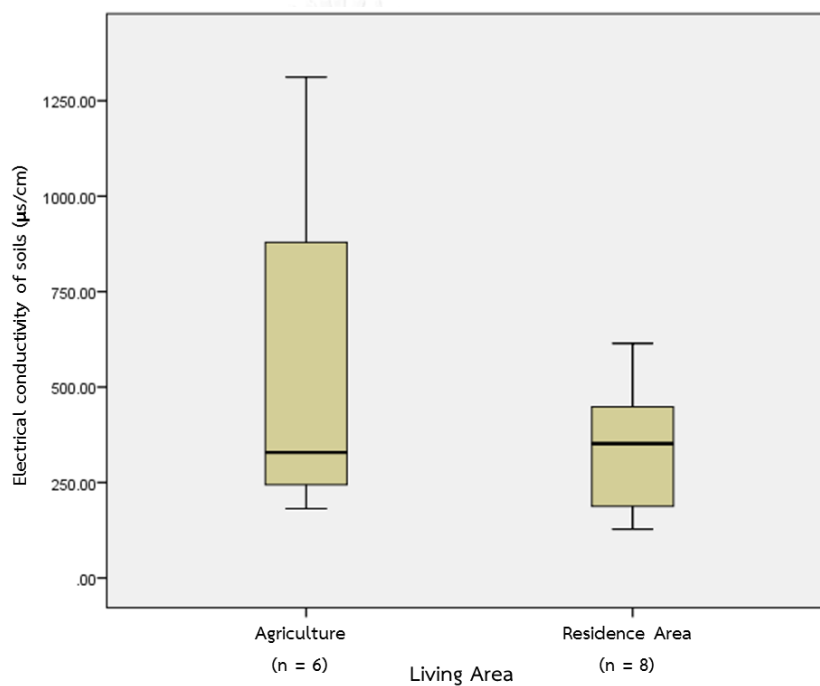


Figure 15. Mercury concentrations on soils in agriculture and residence area

#### 4.2.2 The pH

Agricultural soils were found varied from slightly acidic (pH, 6.5) to slightly basic (pH, 8.55) whereas the soils in residence were found neutral (pH, 7.15) to basic (pH, 9.12). Groundwater acidification was observed at residential sites with

and without agricultural activity. At sites used for agriculture the acidic groundwater was found at a low pH of 5.9 whilst at sites used for residential only the acidic groundwater was observed at a low pH of 6.05. Moreover, among the observed sampling points, the groundwater with high pH was found at site without agricultural activity (pH, 7.90). Results of pH measurement on soils and groundwater indicated those matrices were under the US.EPA standard. Generally, soils at residence with and without agricultural activity were more alkaline than groundwater. A decreasing of soil pH in agricultural sites will relatively drop the pH of groundwater.

#### 4.2.3 Electrical conductivity (EC) and salinity

In average, the EC levels of soils and groundwater was found at the safe limit set by US.EPA (EC, 564 – 5,870  $\mu\text{s}/\text{cm}$ ). The results indicated agricultural activity may increase the EC levels of soils and groundwater. Soils in residence and agriculture were measured with EC at  $339.84 \pm 59.80 \mu\text{s}/\text{cm}$  and  $545.68 \pm 184.40 \mu\text{s}/\text{cm}$ , respectively. The EC levels of shallow groundwater observed in residential site and agricultural field were  $863.06 \pm 130.96 \mu\text{s}/\text{cm}$  and  $1,093.75 \pm 293.20 \mu\text{s}/\text{cm}$ , respectively. By this trend, we can observe an agricultural contribution to an increasing of EC levels on soils, as shown in Figure 16, and in groundwater, as shown in Figure 17. However, this pattern was not consistent for

both soils and groundwater since the difference of EC levels of those both matrices was found not significant.

The maximum EC value in residence was observed exceeded the average values measured in agricultural sites, at 614.5  $\mu\text{s}/\text{cm}$  for soil and 1,701  $\mu\text{s}/\text{cm}$  for groundwater. In agricultural field the peak of soil EC level was at 1,312.05  $\mu\text{s}/\text{cm}$  whilst the EC value of groundwater reached to 2,440  $\mu\text{s}/\text{cm}$  in groundwater. In groundwater, the lowest EC value in site with agricultural activity was observed at 522.5  $\mu\text{s}/\text{cm}$  or 8  $\mu\text{s}$  lower the level in residential area. For soil samples, the lowest value observed in residence area and agricultural site was 127.75  $\mu\text{s}/\text{cm}$  and 181.4  $\mu\text{s}/\text{cm}$ , respectively.

The shallow wells in residence areas contained salinity below the US.EPA compliance for drinking water (less than 0.1%); however one sampling point (GP 5) was found with doubled level than the standard. Sampling sites with agricultural activity exhibited salinity level above the standard exposed to the groundwater ranged 0.05–0.25%. As shown in Figure 18, groundwater at living area with agricultural activity had higher salinity than the saline from residence area with no agriculture.



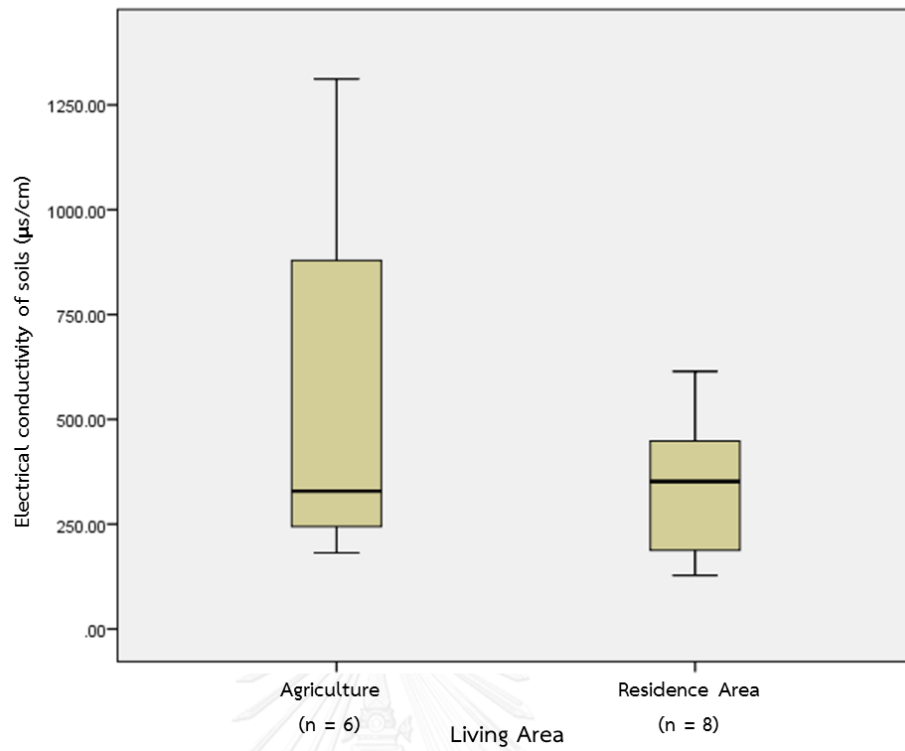


Figure 16. Electrical conductivity of soils in agriculture and residence area

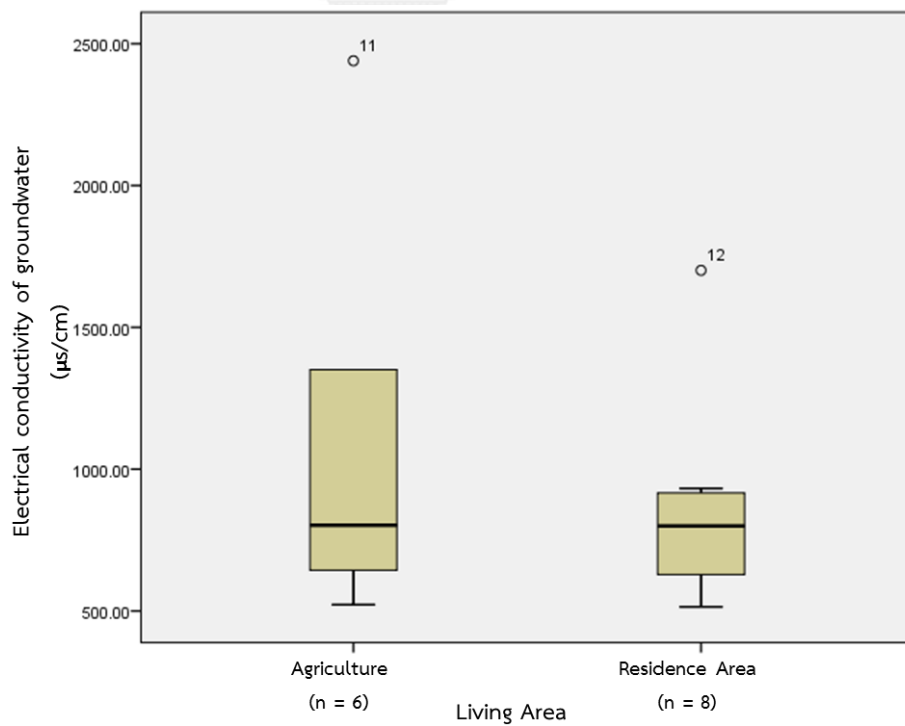


Figure 17. Electrical conductivity of groundwater in agriculture and residence area

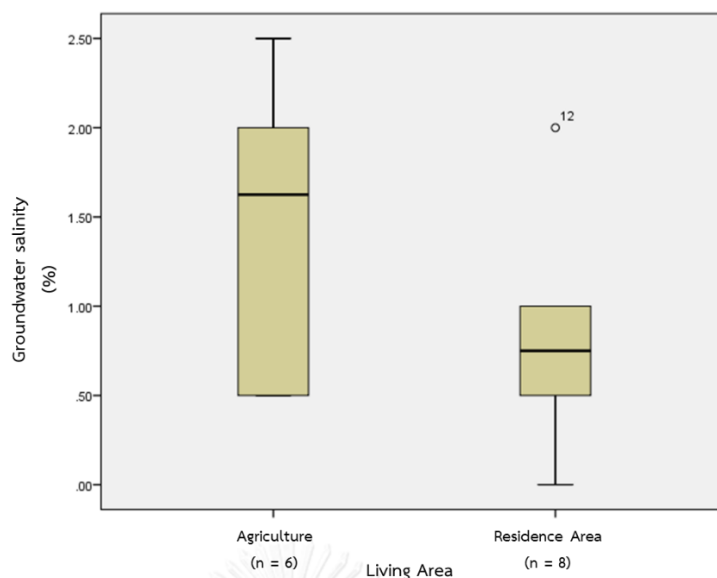


Figure 18. Groundwater salinity in agriculture and residence area

#### 4.2.4 Oxidation-reduction potential

Surprisingly, among the observed sites, agricultural activity contributed relatively to the increasing of ORP level of groundwater, but not to soil samples. ORP levels in groundwater were relatively higher at agricultural sites ( $36.05 \pm 6.77$  mV, ranged 6.71–55.7 mV) than at residence area ( $30.75 \pm 4.80$ , ranged 13.6–53 mV), as shown in Figure 19. Results of ORP measurement of soil samples collected in both agricultural sites and residential areas shows vary distribution from reducing to oxidizing state. Agricultural soils were measured evenly at  $-10.01 \pm 12.04$  mV with a low of -50.6 mV and a high of 17.15 mV whilst soils collected in residence area were observed at  $-9.15 \pm 11.11$  mV, ranged from -65.95–17.57 mV. Agricultural activity relatively decreased the ORP levels of soils, as shown in Figure 20, and resulted with more reducing soils.

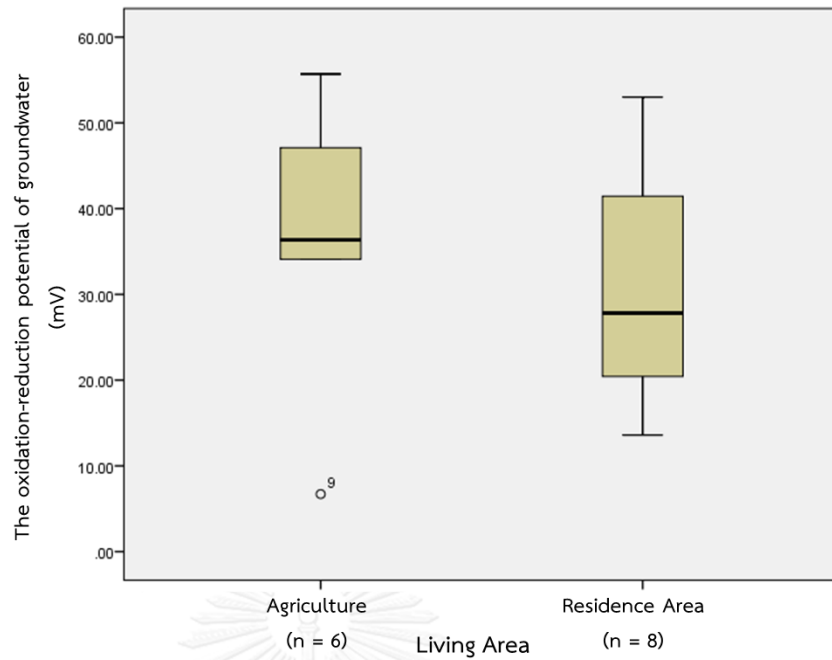


Figure 19. Oxidation-reduction potential of groundwater in agriculture and residence area

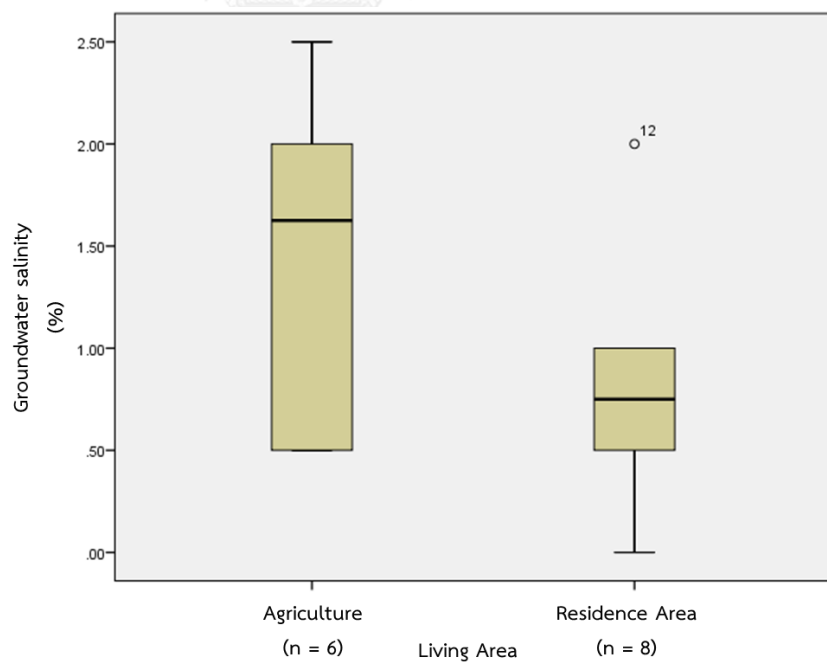


Figure 20. Oxidation-reduction potential of soils in agriculture and residence area

#### 4.2.5 Dissolved oxygen (DO) of groundwater

Agricultural activity contributes to a decreasing of groundwater DO, as shown in Figure 21. Shallow wells in agricultural site had low DO of  $1.63 \pm 0.33$  mg/L ranged between 0.57 and 2.51 mg/L. In average, the DO of groundwater in residential area was  $1.79 \pm 0.22$  mg/L with a low of 1.04 mg/L and a high of 2.82 mg/L. The results indicated no shallow wells met the compliance for dissolved oxygen (US.EPA, DO > 2.8 mg/L).

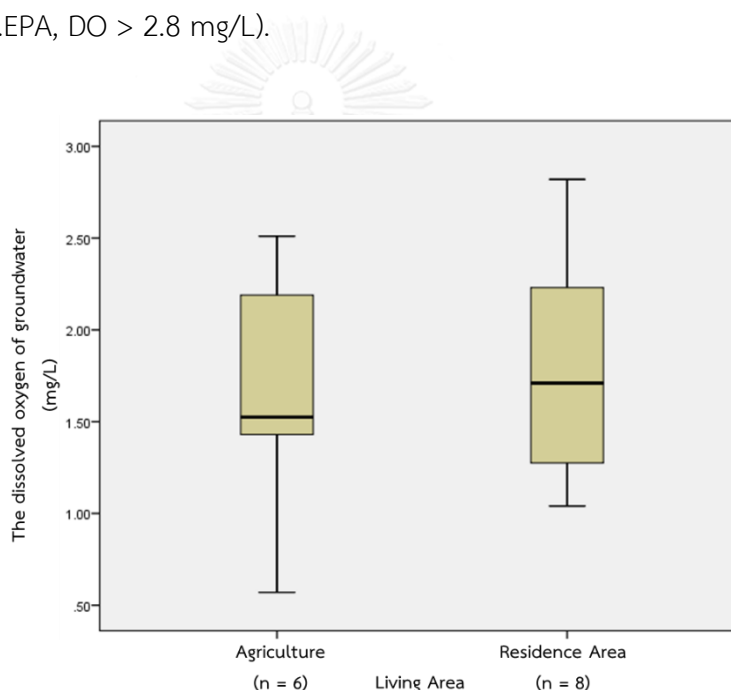


Figure 21. Dissolved oxygen of groundwater in agriculture and residence area

#### 4.2.6 Groundwater temperature

Figure 22 shows groundwater temperature was found higher at agricultural site. In average ( $\pm$  SE), the temperature of groundwater collected from agricultural field and residence area was  $29.29 \pm 0.15^\circ\text{C}$  and  $29.18 \pm 0.10^\circ\text{C}$ . No significant difference between those two monitoring groups with the same peak at  $29.7^\circ\text{C}$ .

The lowest temperature of groundwater found at site with agricultural activity was 28.75°C or 0.05°C lower than the value in residential site.

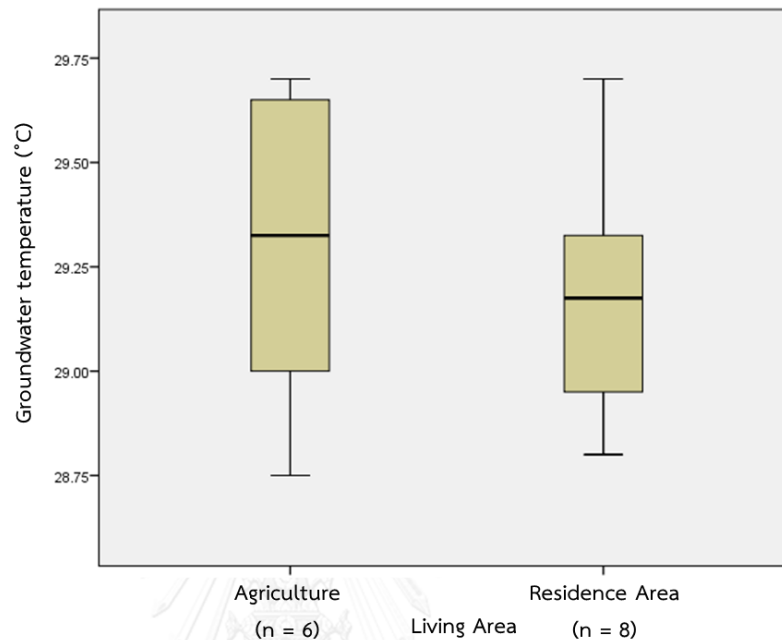


Figure 22. Groundwater temperature in agriculture and residence area

#### 4.2.7 Water percentage and organic carbon matter on soils

Agricultural activity in sampling sites presented an increasing of water and organic carbon percentage on soils (Figure 23). In the two observed gold mining villages, the percentage of water and OMC in soils at agricultural site was  $32.72 \pm 2.76$  with a low of 24.52% and a high of 42.74% whilst soil moisturizer in residence area was in an average of  $21.47 \pm 2.88\%$  and vary distributed ranged 8.21–29.38%. In agricultural field, the organic content was 1.43 times higher than the level in residential area (Figure 24). Organic matter of soils ranged from 2.94 and 7.84 in agricultural field and ranged between 1.25 and 4.87% in residential site.

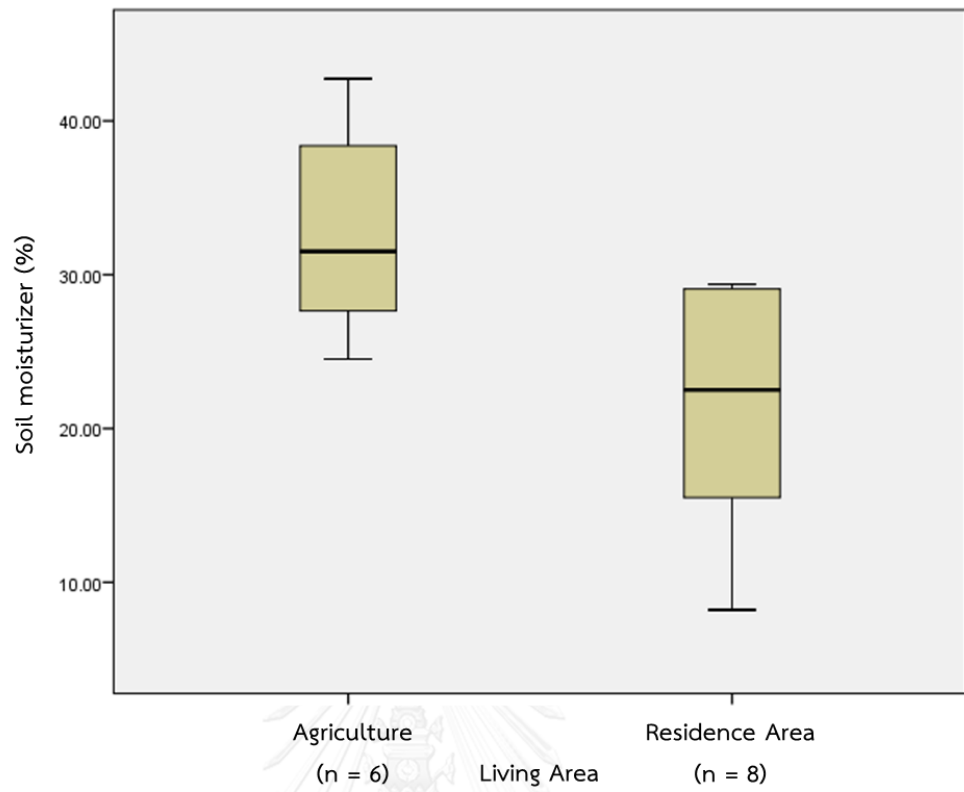


Figure 23. Soil moisturizer in agriculture and residence area

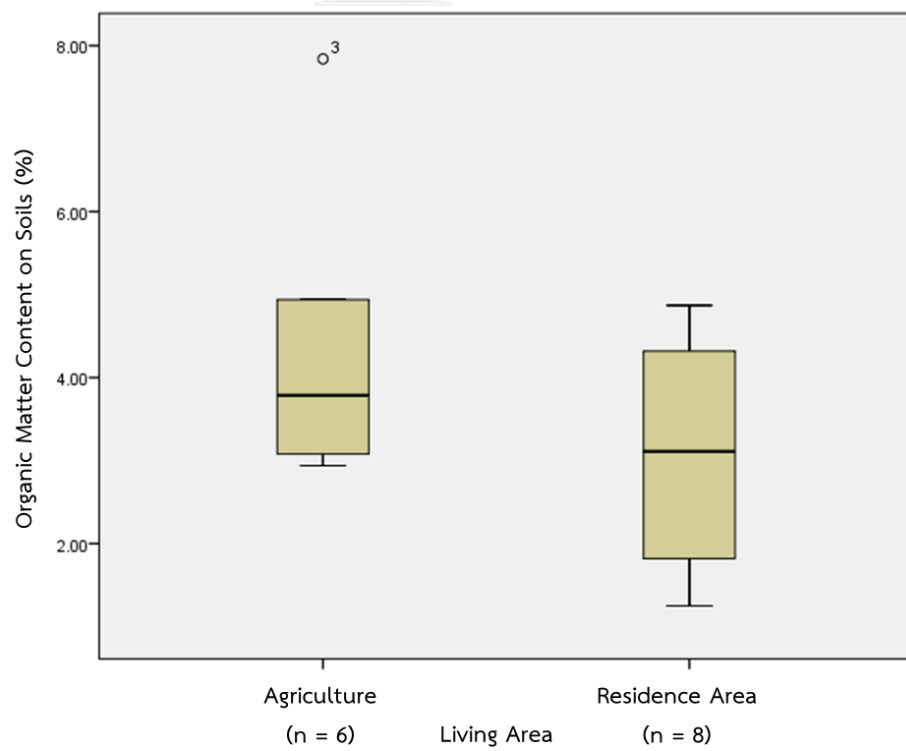


Figure 24. Organic matter content on soils in agriculture and residence area

#### 4.3. The changes of soil and groundwater quality due to gold extraction facility

From the fourteen sampling points at two gold mining villages there were eight locations with active amalgamation, one point with active cyanidation, one site with abandoned cyanidation, two locations with a combination of active amalgamation and cyanidation, and two sampling points with no facility. The contribution of gold extraction facility to the soil and groundwater quality as shown at Table 3.

Table 3. The mean value of soil and groundwater properties at site with and without the gold extraction facility

Matrices	Unit	Process				No Facility (n = 2)	Safe limit <sup>1,2</sup>
		Active Amalgamation (n = 8)	Active Cyanidation (n = 1)	Abandoned Cyanidation (n = 1)	Active Amalgamation and Cyanidation (n = 2)		
<b>Groundwater</b>							
Mercury concentrations	ug/L	0.064	0.170	0.032	1.268	0.084	2
Temperature	°C	29.28	28.80	29.35	29.18	29.20	-
EC	μs/cm	820.31	1701.00	835.50	1477.25	706.75	564-5870
ORP	mV	32.39	26.50	6.71	44.40	40.60	650-700
DO	mg/L	1.75	1.76	1.46	1.38	2.05	> 2.8
Salinity	%	0.07	0.20	0.05	0.18	0.19	0.1
<b>Soils</b>							
Mercury concentrations	mg/L	0.139	0.522	0.570	1.175	0.024	1
EC	μs/cm	351.03	378.00	181.40	751.05	561.58	< 4.000
ORP	mV	-5.87	-65.95	-9.40	-17.45	11.99	-
Water percentage	%	22.80	29.22	32.20	36.06	26.09	-
OMC	%	3.06	3.14	3.08	4.31	5.84	-

<sup>1)</sup> The drinking water safe limit set by US.EPA compliance [50.51], <sup>2)</sup> The soil safe limit set by US.EPA [52-54]

#### 4.3.1 Mercury concentrations

In the two Sekotong's gold mining villages in Lombok Island, Indonesia, mercury concentration was found at all sampling sites. In average, sites with no gold extraction facility had mercury on soils reached to 0.024 mg/kg. The two observed stages of extracting gold – the amalgamation and cyanidation facility – contributed to an increasing of mercury in the soils. The active amalgamation exhibited mercury contamination to soils at 0.139 mg/kg. The data shows the active cyanidation discharged mercury pollution 3.75 times higher than the amalgamation facility. The mercury concentrations on soil at different gold extraction facility was exhibited in Figure 25.

Surprisingly, mercury will still remain in soils at a 2-year abandoned cyanidation facility which contributed to contamination reached to 0.570 mg/kg. It indicated mercury persists on soils for long time. Therefore, consideration to mercury contamination in soils should place at sites with any gold extraction facility existed, even the abandoned facility. The worst scheme appears at site with both active gold extraction facility found. Mercury contamination of soils at site with active amalgamation and cyanidation was above the compliance, and the concentration was significantly different to the levels at site with active amalgamation only.



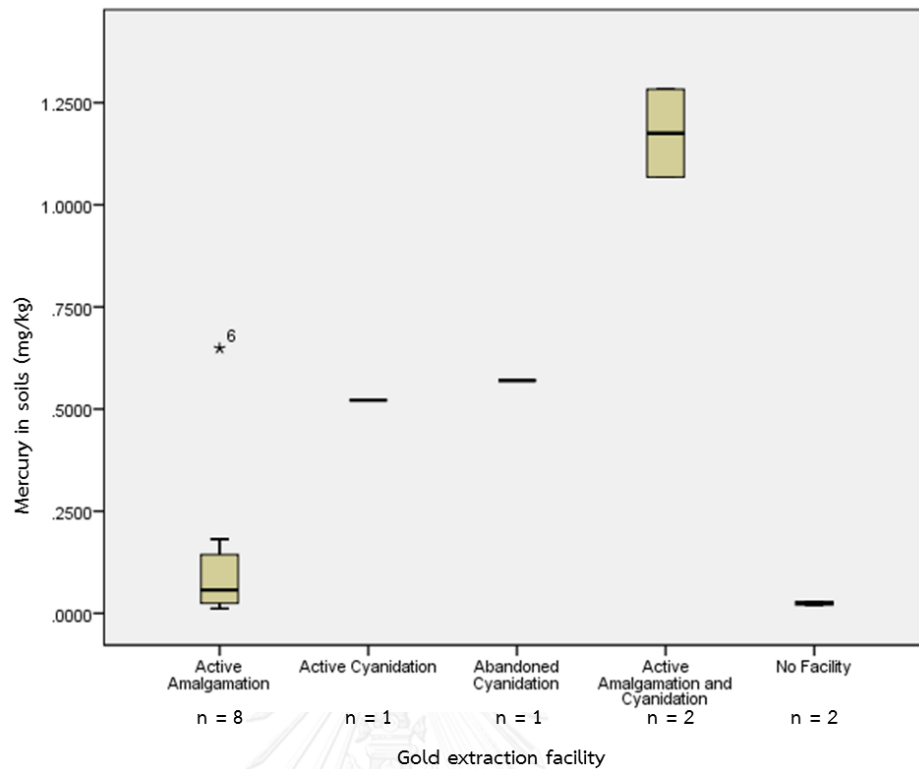


Figure 25. Mercury concentrations on soils at different gold extraction facility

Results of groundwater measurement indicated the shallow wells in two Sekotong's gold mining villages in Lombok Island were contaminated by mercury. Figure 26 exhibited the mercury concentrations on soil at different gold extraction facility. At shallow well with no gold extraction facility nearby the mercury level was found on the average of 0.084 ug/L. It may indicate mercury dissolution in the groundwater system. The lowest mercury concentration of groundwater was found at site with abandoned cyanidation on the average of 0.032 ug/L. The discharging pond at the 2-year abandoned cyanidation facility was insulated by gunny bags filled with clays and stones. Moreover, construction to amalgamating pond also resulted with low level of mercury contaminated on groundwater. At site with

amalgamation facility mercury was measured on groundwater on the average of 0.064 ug/L. However, an increasing of mercury levels of groundwater was observed at site with cyanidation facility evenly at 0.170 ug/L. The discharging effluent of active cyanidation facility was discarded to an excavating pond without cement shell or substrate filling. A combination of active amalgamation and cyanidation increased the mercury contamination of groundwater on the average of 1.268 ug/L.

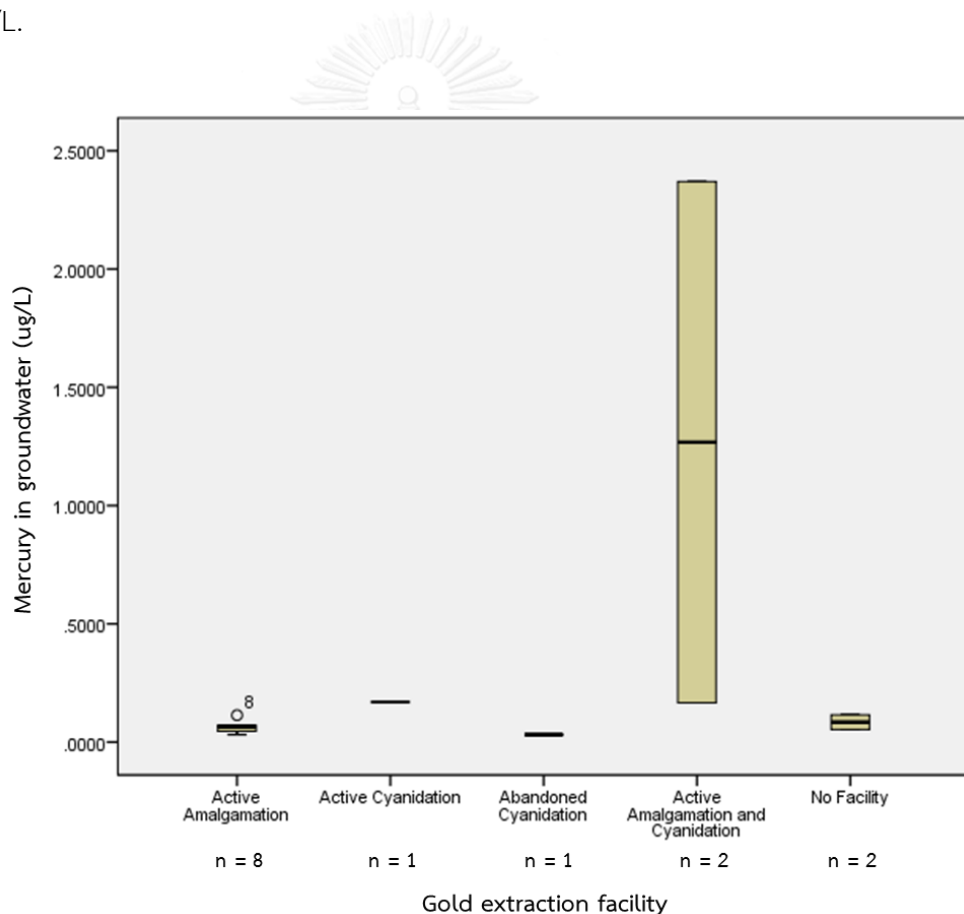


Figure 26 Mercury concentrations in groundwater at different gold extraction facility

Soils at two sampling sites, TE5 and GP4, with cyanidation facility were contaminated by mercury exceeded the regulated level. The significant difference of T-Hg concentrations of soils will be only resulted by cyanidation facility at 0.05

level. Moreover, the presence of agriculture in sampling location GP 4 increased the T-Hg concentration of groundwater 15.9 times higher the level measured in TE 5 where cyanidation facility was found without agricultural activity. The significant difference of T-Hg concentrations of groundwater will be only resulted by cyanidation facility at the 0,05 level. If amalgamation was installed in the backyard of the resident's house, the cyanidation was installed next to the agricultural area. This scary fact suggest the mercury exposure to human through agricultural products should be highlighted.

#### 4.3.2 The pH

During rainy episodes, soil pH at residential area with no facility was found basic ranged from 7.38 to 7.84. An increasing trend of soil pH was found when gold extraction facility placed at the sampling site. At sampling site with active amalgamation the soil pH was at a low of 7.15 and a high of 8.15. Cyanidation facility contributed to an increasing of pH, ranged 9.05–9.19. A decreasing of soil pH was found at cyanidation facility placed with amalgamation facility (pH, 7.77–8.55). Deceasing trend exhibited also at site with abandoned cyanidation. The observation shows at site with a 2-year abandoned gold extraction facility the pH dropped to an acidic level, ranged 6.40 to 6.60. The changes of soil pH were considered in a favorable ranged level for crop production regarding to the plant

availability to use mineral and organic compounds contained in soil set by US EPA (pH, 4.0-9.0).

The 2-year abandoned cyanidation facility was not used as residential area. It exhibited household effluents and high dissolution of rain water in soil particle may contribute to an increasing of soil pH. Interestingly, the acidic soils resulted by the abandoned facility may not deliver mercury dissolution from soils to groundwater. The previous studies found the  $\text{Hg}^{2+}$  desorption, the trend of Hg to release on soil particles, occurs from pH 2 to 4, and adsorption maxima between 4 to 5 [29, 30].

The data shows the shallow groundwater at site with no facility was slightly acidic (pH, 6.05–6.50), but the pH increased to the maximum 7.90 at site with amalgamating process and rose to the peak 7.50 at site with cyanidation facility. It exhibited that the two stages of gold extracting processes may not cause acidification on groundwater in rainy season. Groundwater acidification appeared at residence with or without gold extraction facility. During raining episodes the household discharges may not induce acidification process on soils but it occurred on groundwater system. Moreover, abandoning the cyanidation facility for 2 year may not induce acidification process on groundwater system. The abandoned cyanidation facility had soil pH on the peak of 7.10. However, at site with a combination of active amalgamation and cyanidation facility there was an activity

that may decrease the soil pH to a minimum of 6.10 and a maximum of 7.25. The groundwater pH met the compliance for drinking water set by US.EPA.

#### 4.3.3 Electrical conductivity (EC)

The changes of soil EC still met the compliance for agricultural purposes. The electrical conductivity (EC) in groundwater at different gold extraction facility was shown at Figure 27. In average, the EC level of soils at site with no gold extraction facility was found at 561.58  $\mu\text{s}/\text{cm}$ . EC level exhibited a declining trend at site with active amalgamation or active cyanidation. The soil EC was found evenly of 351.03  $\mu\text{s}/\text{cm}$  at site with active amalgamation, and it was found on the average 378.00  $\mu\text{s}/\text{cm}$  at site with active cyanidation. Cyanidation facility led to vary result to EC levels of groundwater either to decrease to the lowest level in TE 5 or to increase to the highest value in TE 4. The soil EC evenly collapsed at site with abandoned cyanidation at the mean of 181.40  $\mu\text{s}/\text{cm}$ . Surprisingly, an increasing trend of soil EC was found at site with both active facility found, on the average of 751.05  $\mu\text{s}/\text{cm}$ .

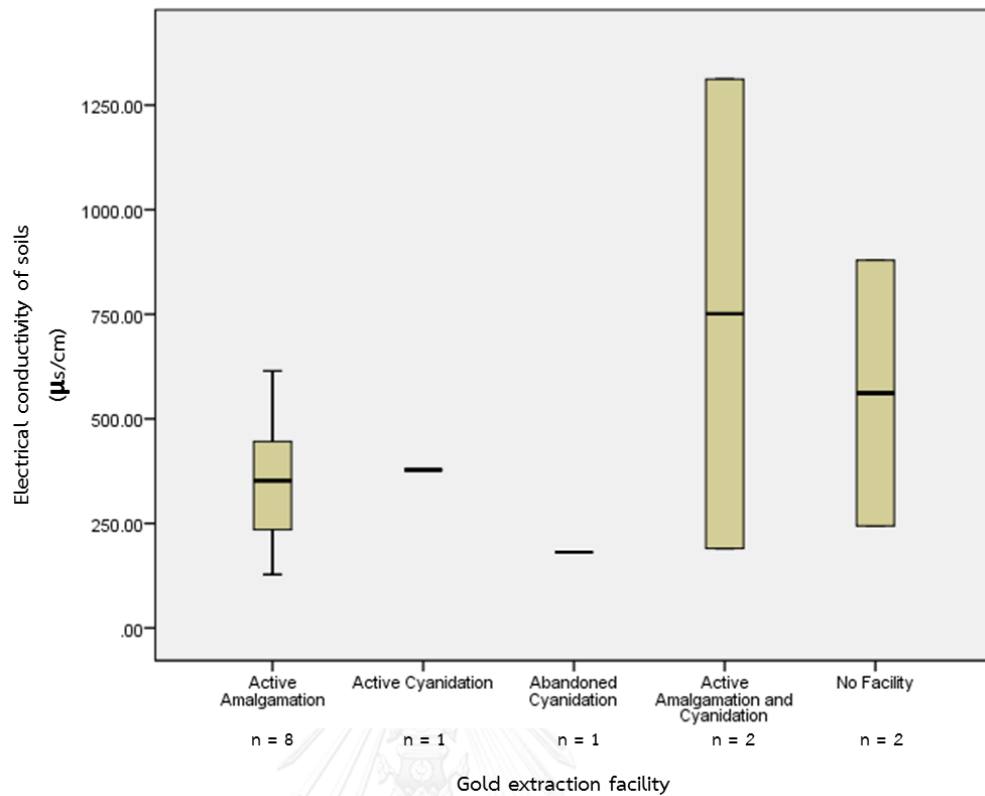


Figure 27. Electrical conductivity in soils at different gold extraction facility

The gold extraction process in the two Sekotong's gold mining villages increased the groundwater EC of the observed shallow wells, as shown in Figure 28. From EC of 706.75  $\mu\text{s}/\text{cm}$  at site with no facility, an increasing of the EC levels of groundwater was observed at site with amalgamating process evenly to 820.31  $\mu\text{s}/\text{cm}$ . Results show the cyanidation process increased the groundwater EC averagely 2.4 times than the level at site without any facility. However, abandoning the cyanidation facility may decrease the EC on groundwater evenly to the EC level of 835.50  $\mu\text{s}/\text{cm}$  whilst combining the active cyanidation facility with amalgamating process slightly decline the EC level on the average of 1,477.25  $\mu\text{s}/\text{cm}$ . The groundwater EC met the US.EPA standard for drinking water.

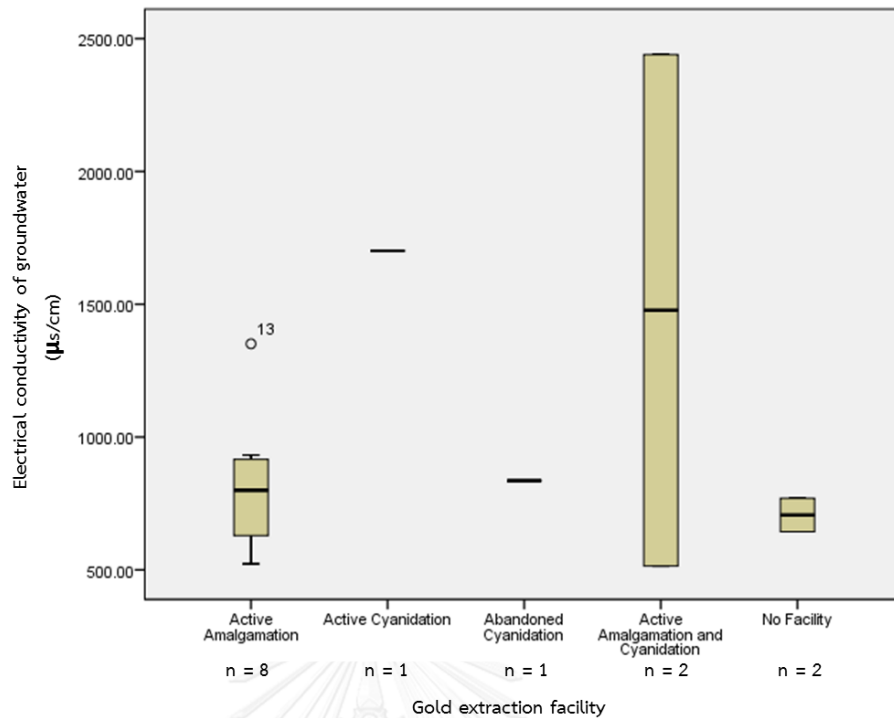


Figure 28. Electrical conductivity in groundwater at different gold extraction facility

#### 4.3.4 Oxidation-reduction potential

Soils at site with no facility exhibited on oxidizing condition on the average of 11.99 mV and it changed to reducing state if any gold extraction facility placed. Active amalgamation facility decreased the soil ORP evenly to -5.87 mV. Cyanidation facility generated an extreme decreasing of ORP soils on the average of -65.95 mV. A decreasing trend was found when combine amalgamating process at site with cyanidation facility on the overage of -17.45 mV. Moreover, abandoning the cyanidation facility for 2 years will increase the ORP soils evenly 7 times, but still on the reducing condition, reached to -9.40 mV. Figure 29 exhibited the oxidation-reduction potential of soils at different gold extraction facility.

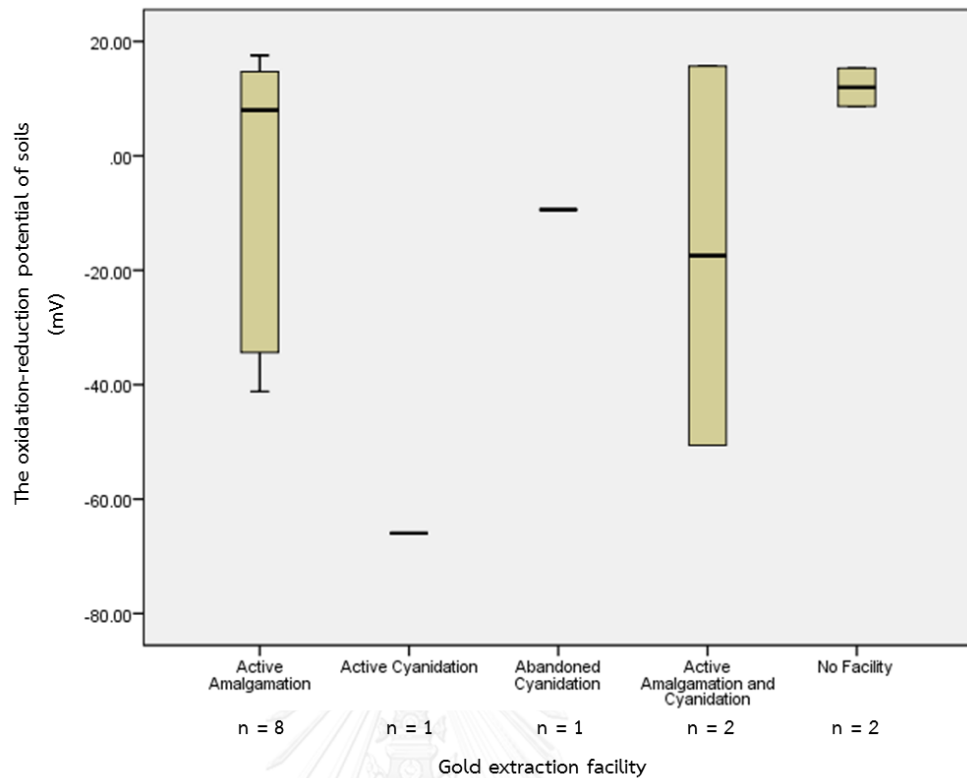


Figure 29. Oxidation-reduction potential of soils at different gold extraction facility

Results of ORP measurement of groundwater samples show water hygiene was an issue in Sekotong's gold mining villages. Figure 30 exhibited a different level of groundwater ORP between one facility to another facility. The two gold extracting processes declined the levels of groundwater ORP. The groundwater ORP measured at site with no gold extraction facility was evenly at 40.60 mV. The depression was found higher in the cyanidation facility (ORP, 26.50 mV) compared to the amalgamation facility (ORP, 32.39 mV). The deepest slope shows at site with the 2-year abandoned cyanidation facility (groundwater ORP, 6.71 mV). Surprisingly, activities at site with a combination of both active facilities may increase the groundwater ORP on the average of 44.40 mV.



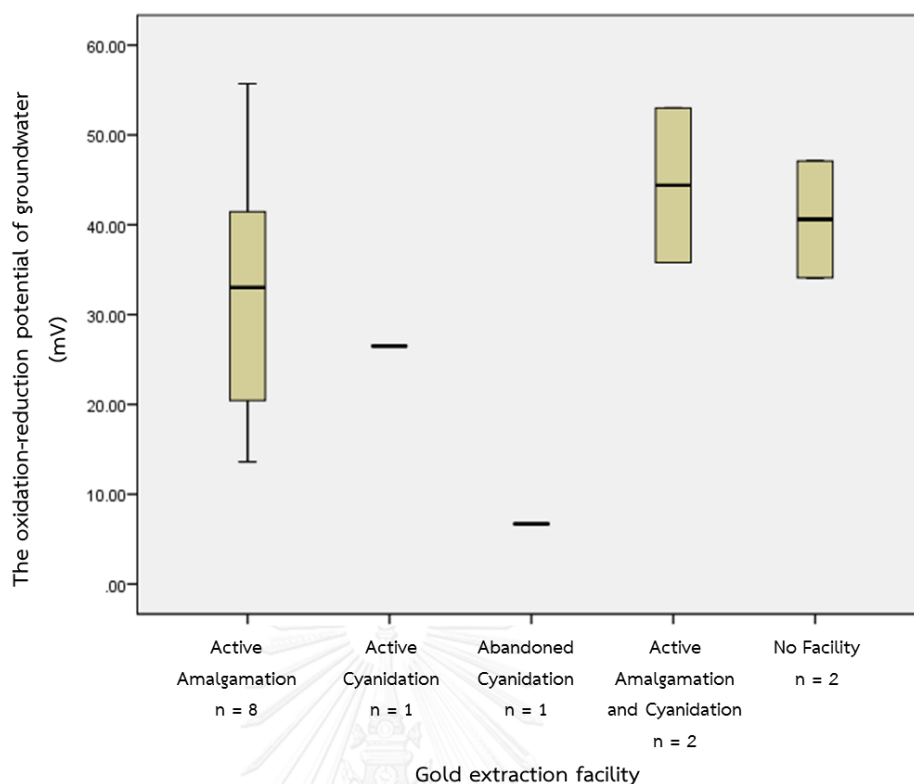


Figure 30. Oxidation-reduction potential of groundwater at different gold extraction facility

#### 4.3.5 Groundwater salinity

Different gold extraction facility contributed varied to groundwater salinity, as shown in Figure 31. Groundwater salinity measured from the shallow wells with no nearby gold extraction facility was evenly at 0.19%. In the average, low groundwater salinity was observed at site with amalgamation facility (0.20%) and at site with abandoned cyanidation facility. Cyanidation process may increase groundwater salinity at the observed sampling site. In the average, groundwater salinity at sampling location with cyanidation facility was doubled than the compliance (US.EPA, 0.1%). Groundwater salinity at location with both two gold

extracting processes was evenly at 0.18 and it was relatively lower than the level without any nearby gold extraction facility. It indicated groundwater salinization might be not a result of gold extraction facility.

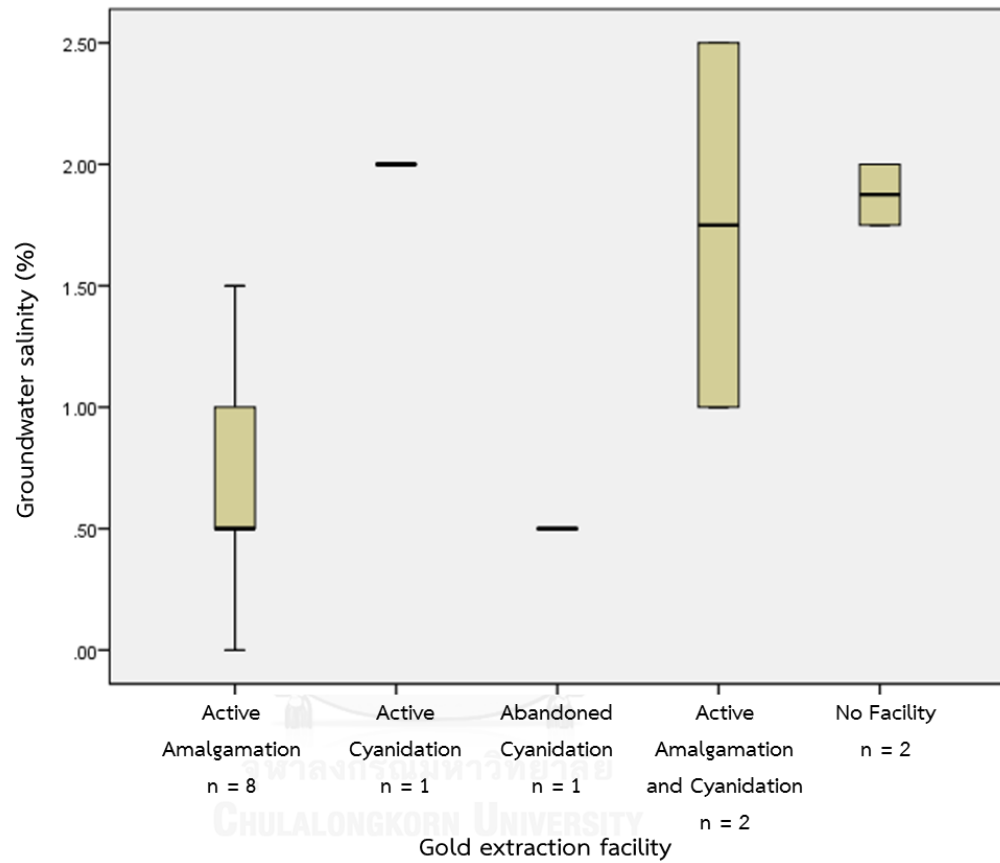


Figure 31. Groundwater salinity at different gold extraction facility

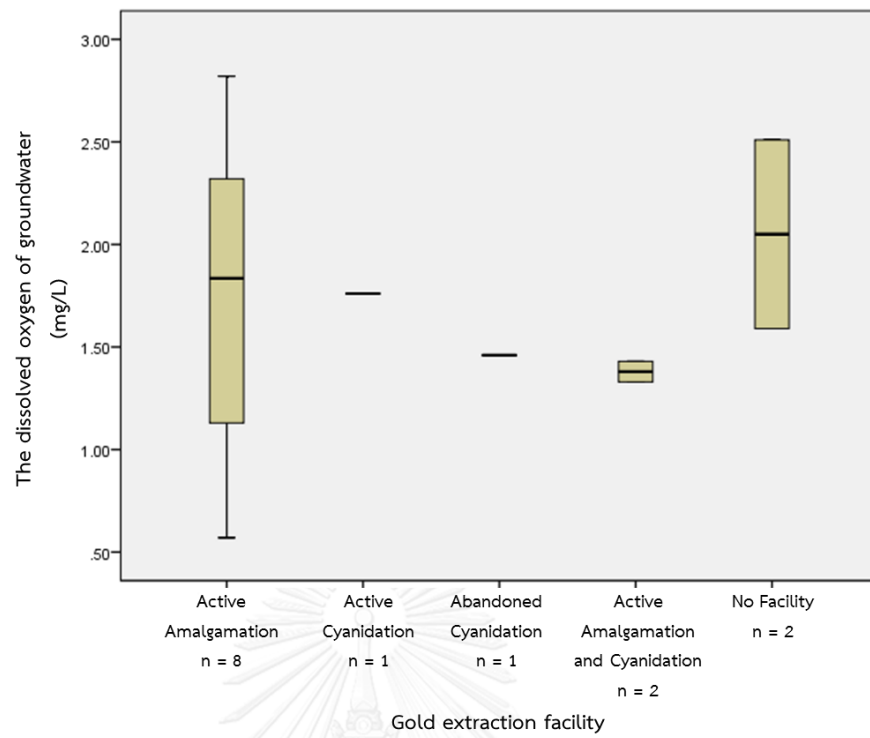


Figure 32. Groundwater dissolved oxygen at different gold extraction facility

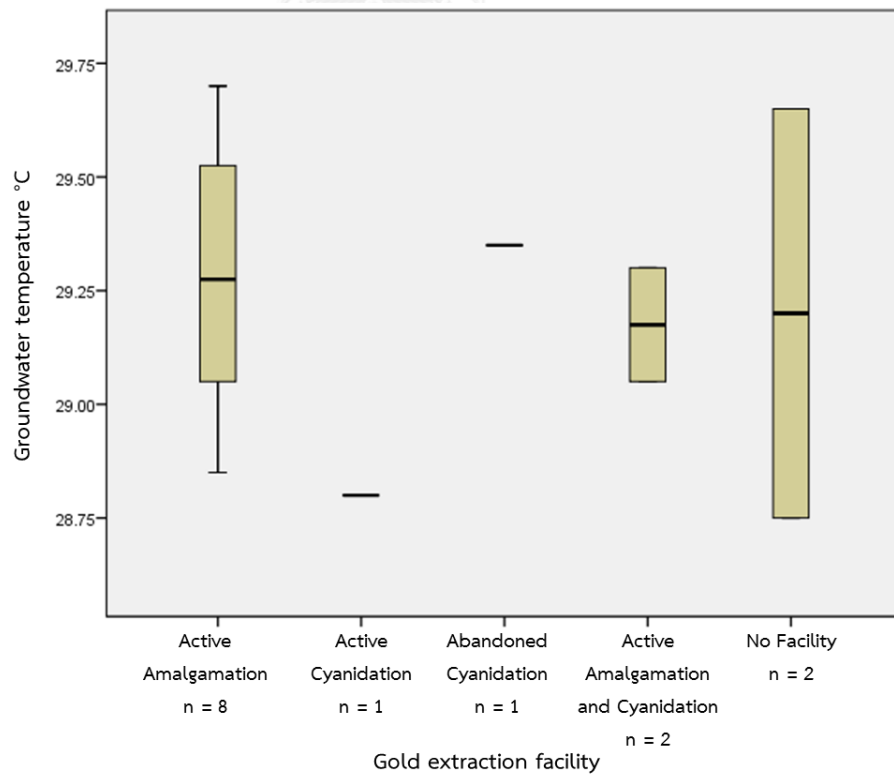


Figure 33. Groundwater temperature at different gold extraction facility

#### 4.3.6 Dissolved oxygen (DO) of groundwater

The shallow groundwater in the fourteen sampling points cannot meet the US.EPA's compliance for dissolved oxygen. The results highlight a decreasing trend of groundwater DO at sites with gold extracting process. The result of groundwater DO at different facilities was shown in Figure 32. The groundwater DO of shallow well collected at site with no gold extraction facility was measured on the average of 2.05 mg/L. The average of groundwater DO decreased to 1.75 mg/L at site with amalgamating process and to 1.76 mg/L at site with cyanidation facility. Leaving the cyanidation for 2 years dropped the groundwater DO evenly to 1.46 mg/L. Moreover, the deepest slope of groundwater DO was observed at site with both two gold extracting processes on the average of 1.38 mg/L.

#### 4.3.7 Groundwater temperature

Regarding to the gold extraction facility at the sampling sites, the variance of groundwater temperature among the sites was found not significantly different. The shallow well groundwater ranged from 28.80°C at sites with cyanidation facility and 29.35°C at abandoned cyanidation facility as shown in Figure 33. The variance is simply caused by the sun light exposure. No shading was found at the abandoned site. Groundwater temperature from shallow well collected at site with active cyanidation facility was measured evenly at 29.28°C. The shading at other sites also caused a relatively lower groundwater temperature than at the

abandoned site. The temperature of groundwater from wells collected at site with active amalgamation and cyanidation facility was evenly at 29.18°C whilst the level measured at site with no facility was on the average of 29.20°C.

#### 4.3.8 Water percentage and organic carbon matter on soils

Figure 34 shows the water percentage of soils at different facility site. Soil moisturizer was found varied among the site from 22.80% at site with amalgamation site to 36.06% at site combining amalgamating process with active amalgamation site. During rainy season, the amalgamation facility which used water in the process had lower water percentage of soils than the levels measured at site with no gold extracting process (26.09%). In average, the cyanidation process will increase the soil moisturizer only 3.13%. Results of soil moisturizer at the 2-year abandoned cyanidation evenly had high moisturizer reached to 32.20%.

Organic matter content on soils was found highest at site with no gold extraction process nearby on the average of 5.84% as shown in Figure 35. At site with both amalgamation and cyanidation processes OMC was measured evenly at 4.30%. Agricultural activity may contribute to an increasing of OMC of soils at the sites. In average, OMC at site with amalgamation and cyanidation process was 3.06% and 3.14%, respectively, and no difference compared to the site with abandoned cyanidation facility at 3.08%.

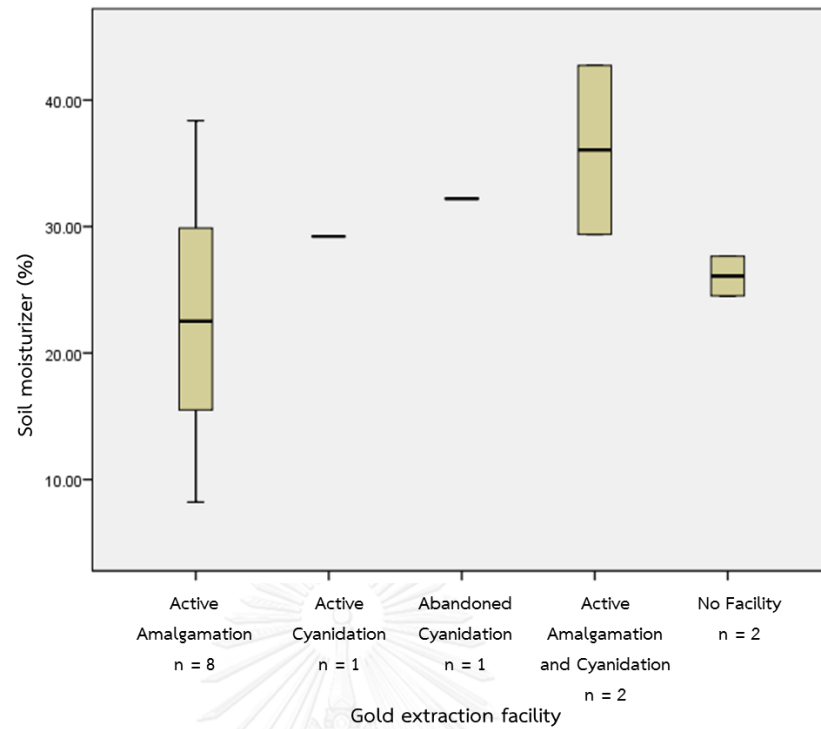


Figure 34. Water percentage on soils at different gold extraction facility

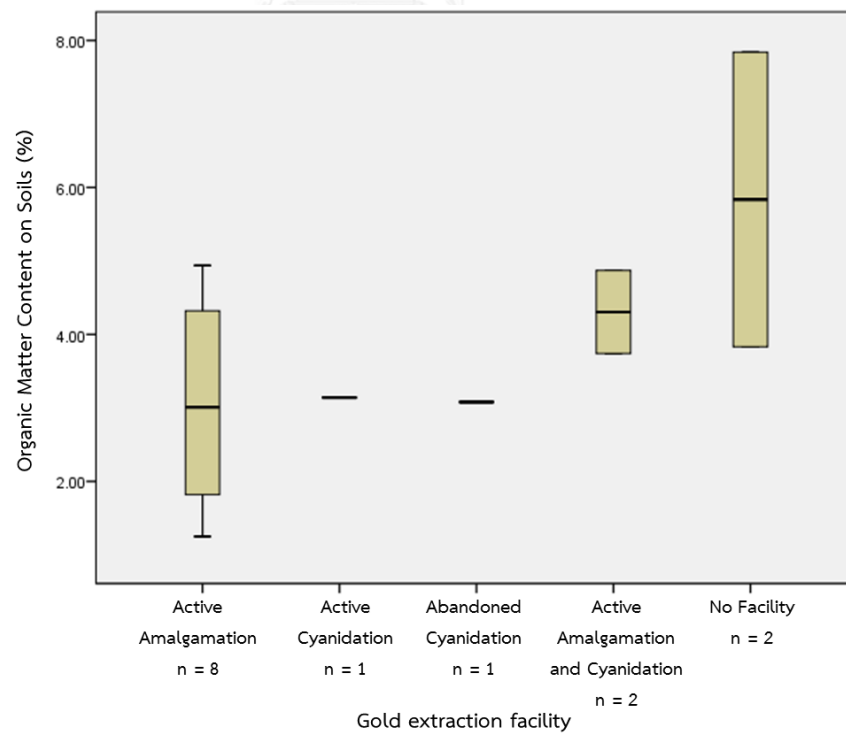


Figure 35. Organic matter content on soils at different gold extraction facility

#### 4.4. River water properties respects to the anthropogenic introduction

Water properties of Merebek river, the nearby river in between the two observed gold mining villages, were measured including mercury concentration, pH, temperature, electrical conductivity (EC), oxidation-reduction potential (ORP), dissolved oxygen (DO) and salinity. The sampling locations of Merebek river water were divided to three zones namely upper, middle and estuary zone, as shown in Table 4. Upper zone refers to the natural background zonation without any suspected human activity. Middle zone represents the zonation with human activity exposure from the nearby villages. Estuary zone located at a transition zone between river environments and oceans.

Table 4. The mean level of Merebek river water properties in 3 zones (upper, middle, and estuary zone)

Parameters	Unit	Safe Limit <sup>1,2</sup>	Sampling Point <sup>3</sup>		
			Upper Zone (n = 2)	Middle Zone (n = 3)	Estuary Zone (n = 1)
Mercury concentrations	ug/L	2	0.115	0.398	1.764
Temperature	°C	-	30.80	31.95	32.70
EC	µs/c m	564-5,870	404.05	499.45	33,230
ORP	mV	650-700	-12.05	-16.65	-35.93
DO	mg/L	> 2.8	4.43	4.23	4.18
Salinity	%	0.1	0	0	2

<sup>1)</sup> The drinking water safe limit set by US.EPA compliance [50.51], <sup>2)</sup> The soil safe limit set by US.EPA [52-54]

<sup>3)</sup> Refers to Figure 2.

#### 4.4.1 Mercury concentrations

Mercury concentration of Merebek river water was found evenly at 0.115 ug/L. If compare to the natural background level, human activity in Sekotong's gold mining villages increased the mercury level of the river water 3.46 times or at the average level of 0.398 ug/L. We highlight an accumulation of mercury at estuary zone reached to 1.764 ug/L or higher 201 times the standard, set by EPA in 1992 (0.012  $\mu\text{g/L}$ ) that used to protect aquatic life [58]. Historically, amalgamation was known as the only step to extract gold in the past few years so that the mercury-containing amalgam mud from the amalgamation process was discarded to the Merebek river.

#### 4.4.2 The pH

Result of river water pH showed the Merebek river was naturally at a slightly acidic condition. At the upper zone, the river water pH was measured at a low of 6.70 and a high of 6.97. An increasing of pH was observed after exposed by village effluents and discharges at low altitude (see Table 5). Compare to the natural background, the level of Merebek river water pH at middle zone ranged from 6.93 to 7.20. During the rainy episodes, the highest pH level was found at estuary zone ranged 7.00–7.20.



#### 4.4.3 Electrical conductivity (EC) and salinity

In average, the EC level in river followed the standard criteria of drinking water and was significantly lower than the level in both villages. A contribution of residential activity was revealed to an increasing of electrical conductivity of groundwater. At natural background, the EC level of Merebek river water was evenly at 404.05  $\mu\text{s}/\text{cm}$  whilst the level after exposed to residence area increased to an average of 499.45  $\mu\text{s}/\text{cm}$ . An extreme increasing of river water EC was highlighted when river water meets the oceans. The EC water at estuary zone was on the average of 33,230  $\mu\text{s}/\text{cm}$ . A very high standard deviation in EC for Merebek river suggests local variation in point source. The freshwater–saltwater transition zone (FSTZ) of this river is the only one sampling point with a very high salinity level.

A very low salinity reached to zero percent was found at natural background and at location with human effluents. Human activity exposure may not increase the salinity levels. However, the denser salinity was revealed in the sampling location of mixing river and ocean. At the estuary zone, the salinity level was observed on the average of 2%.

#### 4.4.4 Oxidation-reduction potential

Results of ORP measurement of Merebek river indicated that during rainy season the river water was on reducing state. The ORP level was found decreased

after passed the villages and made it more favorable as reducing agent. The ORP of river water at natural background was evenly at -12.05 mV whilst after human exposure at middle zone the level decreased to an average of -16.65 mV. When the salt and fresh water are mixed at estuary zone, contrary to EC levels, an extreme decreasing of EC values was revealed.

#### 4.4.5 Dissolved oxygen (DO) of river water

In contrast, the DO level of Merebek river, ranged from 3.71 to 4.63 mg/L with an average value of 4.30 ( $\pm 0.25$ ). Using Kruskal-Wallis test, the results show the river water was significantly higher than the level in both the subjected villages ( $p$  value  $< 0.001$ ). During the rainy season an increase of river water flow rate increases the high water dissolution and air surface contact resulted with an increase of the oxygen levels.

At Merebek river, the dissolved oxygen was found at natural background on the average of 4.43 mg/L. High substrate and air mixing during rainy episodes may increase the DO of river water. However, the DO level was found declined with a decreasing of altitude. Human activity and effluent exposure to river water may contribute to a decreasing of DO water. During rainy season the DO of river water at sampling location nearby residential area was evenly at 4.23 mg/L. The DO level continually decreased at estuary zone where river environments meet the oceans to an average of 4.18 mg/L.

#### 4.4.6 Temperature of river water

An increasing of water temperature in river might be resulted by sunlight exposure. Moreover, the data shows a rising of temperature of Merebek river water was found with a decreasing of elevation. In the average, the temperature at upper zone was measured at 30.8°C. After passing the villages the temperature increased evenly at 31.95°C. Results exhibited the highest temperature of Merebek river water was observed at estuary zone on the average of 32.7°C. The water mixing from the oceans may contribute to the increasing of river water temperature.

#### 4.5. Depth to water surface influencing to soil and water properties

Depth to water surface refers to a measurement of distance of groundwater surface of each observed shallow well to soil surface. It indicated the length of soils to the groundwater resources. Using Spearman product moment correlation, a positive correlation was exhibited when correlate the depth to water surface to altitude at significant level 0.05. It indicated the altitude contribute to an increasing of the distance of soil surface to the groundwater resource. As the result, the soils at sampling point with low altitude have high soil moisturizer ( $r_s = -0.648$ ) and significantly different at 0.05 level. Table 5 exhibited a decreasing trend of the values of other soil properties to an increasing of elevation, including mercury concentrations, pH, EC, and OMC. On other side, at high altitude location the soil ORP increased very largely at the 0.01 level.

Table 5. Correlation between the depth-to-water-surface of shallow wells to altitude, volumes of amalgamation ponds, and properties of soils and groundwater

Parameter	Spearman Correlation Coefficient (rs)		
	Depth to water surface	Volume of amalgamation ponds	Altitude
Volume of amalgamation ponds	0.682**		
Altitude (m)	0.587*	0.224	
Groundwater (n = 14)			
Mercury concentrations	- 0.436	- 0.157	- 0.349
pH	- 0.369	- 0.214	0.074
Temperature	0.370	0.088	0.479
EC	- 0.745**	- 0.524	- 0.335
ORP	0.160	0.267	- 0.163
DO	0.354	0.178	0.329
Salinity	- 0.631*	- 0.450	- 0.612*
Soils (n = 14)			
Mercury concentrations	- 0.314	- 0.016	- 0.278
pH	- 0.398	0.009	-0.415
EC	- 0.354	- 0.202	-0.337
ORP	0.815**	0.478	0.395
Water percentage	- 0.648*	- 0.280	-0.381
OMC	- 0.119	- 0.148	-0.162

\*\* Correlation is significant at the 0.01 level (2-tailed).

\* Correlation is significant at the 0.05 level (2-tailed).

The Spearman correlation test between the elevation of sampling point and the groundwater properties shows the groundwater EC and salinity will increase significantly, respectively at significant 0.01 and 0.05 level, at low altitude location. Similar to the mercury concentrations and pH of soils, the analysis exhibited a moderate decreasing trend of these parameters on soils. Other groundwater properties, including temperature, ORP, and dissolved oxygen relatively increased with a rising of sampling point elevation.

#### 4.6. Impacts of volume of amalgamation ponds to soil and groundwater properties

The results, shown in Table 5, exhibited was a tendency of miners living in high altitude locations to construct an amalgamation pond with higher volume. The residents settled near the sea prefer to work as farmer and fisherman. The largest amalgamation pond was found at highest altitude location. The volume of amalgamation volume increased largely with a rising of elevation. At the high altitude sampling points, the depth of the unsaturated zone was large. It may also affect relatively to the negative correlation between mercury concentrations of groundwater and the amalgamation ponds. It indicated no direct contribution of amalgamation ponds to the mercury contamination of the observed shallow wells.

As shown in Table 5, an increasing of the volumes of amalgamation ponds, as the subjected mercury-discharging sources, will be not resulted with an increasing of mercury concentrations in environment. It exhibited there was no contribution of the volume of amalgamation pond to mercury concentrations on soils. The results indicated no vertical and horizontal distribution of amalgamation discharge at the observed locations. The data shows the T-Hg levels accumulated in soil were not considered as a result from tailing load leachate. The mercury contamination may come from the transportation step when the load needed to be packaged in plastic gunny then sent to cyanidation facility. The miners prevent the pond from a filling by rain water that caused the loss of gold-containing discharges. This result supports that there is high awareness of people to prevent the leachate from tailing load in order to avoid the worthy material lost before transported to the next gold extraction process.

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#### 4.7. Correlation among groundwater properties

Spearman's test was used to analysis the correlation between one parameter of groundwater to other groundwater properties. The results shown at Table 6 exhibited a rising of salinity significantly increased mercury accumulation in groundwater at the 0.01 level (Spearman's Correlation Coefficient  $r_s = 0.577$ ). The high salinity may relate to mercury precipitation in groundwater. An increasing of groundwater salinity may correlate to a rising of groundwater pH, EC, and ORP.

On other side, the groundwater salinity will relatively decreasing with an increasing of temperature and may generate a decreasing trend to the groundwater DO.

Table 6. The Spearman's' correlation among groundwater properties (n=14)

Groundwater properties	Spearman's Correlation Coefficient, rs (n= 14)					
	Salinity	DO	ORP	EC	Temperature	pH
Mercury concentrations	0.577*	- 0.169	0.233	0.279	- 0.391	0.203
pH	0.166	- 0.301	- 0.772**	0.611*	- 0.275	
Temperature	- 0.299	0.123	0.106	- 0.278		
EC	0.364	- 0.499	- 0.473			
ORP	0.140	0.204				
DO	- 0.133					

\*\* Correlation is significant at the 0.01 level (2-tailed).

\* Correlation is significant at the 0.05 level (2-tailed).

The results exhibited an increasing trend of groundwater DO to the decreasing of mercury concentrations of groundwater. The DO of groundwater will relatively rise with an elevation of groundwater temperature and will follow with an enhancement of ORP values of groundwater. However, an increasing of DO will relatively drop the groundwater pH and EC. As shown in Table 6, groundwater pH has strong relationship to the EC, so that a decreasing of groundwater pH will significantly drop the groundwater EC at the 0.05 level ( $r_s = 0.611$ ).

It revealed the more reducing follows with the lower mercury concentration on groundwater. Table 6 shows a decreasing of ORP will exhibit a decreasing of

mercury levels of groundwater. The ORP on the groundwater has a very strong correlation to the pH where as one variable increase, the other variable will drop ( $r_s = -0.773$ ) at the 0.01 level. The results exhibited an increasing of temperature may play a minor role to promote an elevation of ORP values of groundwater. The rise of ORP may moderately decrease the EC of groundwater as the result.

The results show a relatively increasing of EC levels of groundwater when the mercury levels increased, however the EC level of groundwater may decrease by an increasing of temperature. The level of mercury and pH of groundwater will also relatively drop with an increasing of temperature. Moreover, among the observed shallow wells, the pH condition is favor for mercury dissolution. Groundwater with high pH tends to have high mercury concentration.

#### 4.8. Correlation among soil properties

Spearman test was used to analysis the correlation between one parameter of soil to other soil properties. Table 7 exhibited a corresponding relative increasing of organic matter content (OMC) on soils with the level of mercury on soils and its moisturizer. A rising of OMC on soils gives small contribution to an increasing of soil capacity to hold mercury in its particles. The organic matter may either act as a sorbent or provide high concentrations of dissolved ligands that form very strong complexes to Hg (II), as reviewed by Randall and Chattopadhyay [37]. The soil capacity will accommodate more OMC if water percentage on soils



increased. Organic matter on soils will relatively increase the soil ORP, but will give small drop to soil pH.

During rainy season the soil pH was alkaline. The high rain water dissolution increased the soil pH. Result shown in Table 7 shows a corresponding relative increasing of pH with water percentage of soils. A rising of pH on soils dropped the ORP moderately. The soil pH also plays role to level of mercury on soils. Table 7 shows that at site with high alkalinity tends to have high level of mercury on soils. It may indicated soils the alkaline soils may hold the mercury on its particle so that an increasing of soil pH may prevent mercury transportation on soils.

Table 7. The correlation among soil properties

Soil properties	Spearman's Correlation Coefficient (rs) (n = 14)				
	Organic matter content	Water percentage	ORP	EC	pH
Mercury concentrations	0.275	0.798**	- 0.187	0.059	0.262
pH	- 0.229	0.108	- 0.407	0.631*	
EC	- 0.092	- 0.033	- 0.473		
ORP	0.244	- 0.393			
Water percentage	0.372				

\*\* Correlation is significant at the 0.01 level (2-tailed).

\* Correlation is significant at the 0.05 level (2-tailed).

Results of Spearman analysis exhibited the significant correlation between soil moisturizer to mercury levels. It indicated water percentage on soil generates a very high contribution to hold the mercury on soil particles, however, the

contribution of water content on soil to an increasing of soil pH was found insufficient. Similar with Liang *et. al.* [36] found a significantly strong positive correlation was found between T-Hg when the land flooded. Briggs and Gustin [34] also discovered a suppressed Hg-emission when the soils were saturated. It concluded that the more water contained in soil, the more T-Hg retained.

An increasing of soil ORP will moderately decrease the soil pH, but an elevation of soil EC will significantly increase the soil pH at 0.05 level. Moreover, a negative correlation was found between soil ORP and soil EC ( $r_s = -0.473$ ) and water content on soil ( $r_s = -0.393$ ). Moreover, from Table 7, a very small effect of an increasing soil moisturizer was found to a decreasing of soil EC.

#### 4.9. Correlation between soil and groundwater properties

Table 8 refers the correlation coefficient between soil and groundwater properties from Spearman correlation test. It exhibited a small contribution of mercury concentration on soils to an increasing of mercury contamination in groundwater. Surprisingly, an increasing of mercury concentrations of groundwater was also found at sampling location with moderately high water percentage, pH, and organic content on soils. However, a moderately precipitation of mercury in groundwater was revealed with an increasing of soil ORP. Soil EC contributed at minor for mercury leaching to groundwater.

Groundwater pH had a very strong correlation to soil ORP where this parameter will significantly decrease the pH at groundwater system at the 0.01 level. The results show organic matter carbon on soils correlate to acidification on groundwater system. A very small contribution of mercury concentration on soils was found related to decreasing pH levels of groundwater. It was a very small correlation between pH and water content of soils to groundwater pH. However, soil EC shows a moderate correlation to an increasing of groundwater pH as shown in Table 8.

Table 8. Correlation between soil and groundwater properties

Matrices	Spearman Correlation Coefficient (rs)						
	Groundwater properties (n = 14)						
	Mercury concentrations	pH	Temperature	EC	ORP	DO	Salinity
Soil properties (n = 14)							
Mercury concentrations	0.262	- 0.100	0.276	0.165	0.244	- 0.464	0.226
pH	0.330	0.062	- 0.304	0.569*	0.248	- 0.121	0.240
EC	0.095	0.343	- 0.029	0.596*	- 0.095	- 0.147	0.434
ORP	- 0.304	- 0.723**	0.406	- 0.895**	0.543*	0.481	- 0.495
Water percentage	0.328	0.015	0.020	0.262	0.187	- 0.442	0.477
OMC	0.314	- 0.381	0.264	- 0.422	0.568*	0.200	0.457

\*\* Correlation is significant at the 0.01 level (2-tailed).

\* Correlation is significant at the 0.05 level (2-tailed).

The results show high temperature of groundwater was relatively found at sampling points with relatively high mercury concentrations, soil ORP and organic matter content on soils. The results highlight an increasing of temperature may correlate to acidification on soils. Soil pH generated a positive correlation to groundwater EC significantly at the 0.05 level. Soil EC also exhibited a significant

contribution to an increasing of groundwater EC ( $r_s = 0.596$ ) at 0.05 level. A positive trend for groundwater EC was also found to other soil properties including mercury concentrations and water percentage. However, groundwater EC was found decreased by a rising of soil ORP and OMC where soil ORP contributed significantly at very strong scale at the 0.01 level ( $r_s = -0.895$ ) as shown in Table 8.

Table 8 shows an increasing of groundwater ORP was significantly related to a rising of ORP ( $r_s = 0.543$ ) and OMC ( $r_s = 0.568$ ) measured on soils at the 0.05 level. The same rising trend of groundwater ORP was also found related to an elevation of other soil properties including mercury concentrations, pH, and soil moisturizer. Soil EC delivered a very small contribution to a decreasing of groundwater ORP.

From the results shown in Table 8, a negative correlation was found between mercury concentration on soils and DO in groundwater. Soil moisturizer will also decrease moderately a level of groundwater DO. The same trend was also found for pH and EC of soils where these parameters known related to the deep slope of groundwater DO. Contrary to pH and soil EC, soil ORP and OMC on soils attributed to an increasing of groundwater DO.

High salinity of groundwater was found at location with high mercury concentrations on soils. Salinity in groundwater system may correlate to an increasing of soil properties including pH, EC, and OMC. Surprisingly, high groundwater salinity was found at sampling location with high moisturizer on soils.

We also revealed a low level of ORP on soils moderately correlated to an increasing of salinity in groundwater system as shown in Table 8.

#### 4.10. Natural attenuation to remediating the mercury contamination

The water dissolution to soil particles, in rainy season, increases the alkalinity of soils and water resources. An increasing of pH of soil samples increased the EC of soil and water resources significantly. An increasing of pH of water resources significantly reduced the ORP of soils and water resources. As per by New Jersey Department of Environmental Protection in their site remediation program in 2012 [59], the high level of electrical conductivity (EC) and salinity, and the negative ORP value may trigger nature attenuation for contaminated soils and water resources. Based on the observed results, natural attenuation may be suggested to reduce the T-Hg concentrations of soil and water resources in these both subjected gold mining villages. The EC levels of groundwater shows a negative relationship to the altitude of sampling points and ORP, but produces a positive relationship to the salinity. These relationships suggest the high potentiality of natural attenuation to occur naturally in the low-altitude sampling points.

The sun-light exposure, represented by an increasing of temperature, significantly reduced the ORP levels of water resources and increased the DO. The negative correlation shown between the T-Hg concentrations and the DO of groundwater shows the oxidation or Hg methylation microbial process may be

occurred in contaminated sites [37]. The increasing of DO will also significantly decrease the ORP level of water resources. It suggests open contact to sun-light and air might be considered to increase the potentiality of natural attenuation to remediate mercury contamination in soils and groundwater. Moreover, temperature facilitates the increasing of vapor pressure and the thermal motion of the Hg compounds then contributes to the lower concentrations of T-Hg in groundwater [28].

#### 4.11. Low mercury dissolution in groundwater

The pH of groundwater plays important role to mercury dissolution. The alkaline condition of pH of groundwater may not deliver mercury dissolution in groundwater. The most alkaline groundwater samples were found at the highest altitude, in TE 1 and GP 1 as shown in Table 10 at Appendix A, and used only for residence. As shown in Table 5, the groundwater pH level will relatively decrease and becomes acid with altitude decreased since human activity accumulated, however the altitude was not significantly associated to the level of groundwater pH ( $r = -0.323$ ,  $p$  value = 0.259). The acidity of mining effluents and agricultural activity may lead acidification of groundwater [60, 61]; however the high dissolution of rain water to groundwater suggests an increase of pH [62]. Rolffhus and Fitzgerald [41] suggested that to increase of labile Hg (II) to promote the reduction of abundant Hg organic complexes and drives to reducing the T-Hg

concentrations in water and enhancing the Hg (0) production on sediment. In this observation, as shown in Table 5, salinity of groundwater increased significantly to the low elevation at the 0.01 level ( $r_s = 0.612$ ), and it may result a low mercury dissolutions at low-altitude point areas. The level of salinity of groundwater may trigger mercury precipitation and reduce the T-Hg concentration of groundwater.

#### 4.12. Mishandling mercury-containing amalgam mud and the atmospheric mercury contribution

As explained in 4.6 part, and the data shown in Table 5, the amalgamation facility has no relation to mercury contaminations on soil. This result shows the amalgamation facility not considered as a mercury contamination resource in soils. A high awareness of miners was observed to prevent the leaching from amalgamation tailing load in order to avoid the worthy material lost before transported to the next gold extraction process. The mercury contamination in soils collected nearby the amalgamation pond may come from the transportation step. The mercury-containing amalgam mud was packed in plastic gunny then sent to cyanidation facility. The mishandling amalgam mud may contribute mercury contamination on soils.

#### 4.13. Organic matter as the further problem of mercury contamination

For the observed parameters, only soil moisture generated a significant and positive correlation to the Hg concentrations of soils, and this parameter was

significantly affected to agricultural activity. The soil will significantly be more moisture when the distance to groundwater decreased. The more water retained on soils, the more alkaline the soils and may prevent mercury leaching from soils to groundwater. However, during the rainy episodes, the high rain water dissolution may deliver more organic matter to groundwater. The organic matter of soils and the uses of fertilizers may reduce the alkalinity and promote acidification [63]. A decrease of soil pH significantly reduce the EC levels of soil and groundwater, and may increase the ORP level of groundwater. As the result, a drop to soil pH may prevent mercury precipitation. It suggests the waste of agriculture, household, and animal husbandry in these study areas may generate further problems of inducing mercury mobilization from soils to groundwater and also prohibit natural attenuation occurred in groundwater to remediating the mercury contamination. The effort to maintain high level of EC of soil may be also considered to trigger the natural attenuation occurred in groundwater since the EC of soil contributes positively to the EC of groundwater.



## CHAPTER 5. CONCLUSION

This research received information related to the quality of soils and water resources during rainy season in two massive gold mining village in Sekotong regency, Lombok, Indonesia, and the nearby river named Merebek river. The compliance set by US.EPA was used to determine the safe limit. The data shows gold extracting processes involved in the residence charge mercury burden to soils and groundwater. Even though the concentration was observed under the safe level, mercury was found dissolved in groundwater system and settled on soils.

The results exhibited no vertical and horizontal distribution of amalgamation discharge at the observed locations. Cyanidation facility contributes significantly to mercury contaminations on soils and groundwater. The data shows the flooding in resident area during the rainy season may not lead to the leaching of mercury to environment, but mishandling mercury-containing waste mercury may consider as the sources. This result supports that there is high awareness of people to prevent the leachate from tailing load in order to avoid the worthy material lost before transported, but no consideration to cyanidation tailing pond. Moreover, an insulated discharging pond at the 2-year abandoned cyanidation facility by gunny bags filled with clays and stones may prevent vertical transportation of mercury from soils to groundwater, but not horizontal contamination. The results suggest a highly priority need to be given to

cyanidation facility, but the two gold extraction facility will contribute to mercury contaminations on soils and groundwater, even the abandoned facility.

Based on data observation there is a possibility of natural attenuation involved in mercury remediation in groundwater and soils at subjected area. The alkaline groundwater and soils, in rainy episodes, may prevent the mercury dissolution and increase the soil capacity to 'hold' the contamination in soil particles, and may contribute to natural attenuation. However, further research may deserve to find out how a variety of reactions in soil environment trigger the natural attenuation to remediating mercury in soils and groundwater.

Respecting to the anthropogenic introduction, the river water properties were found with an increasing of mercury concentrations, pH, temperature, and EC; but no changes to salinity. After passed the villages, river water became more reducing and the DO was decreased. When the salt and fresh water are mixed at estuary zone, there was a high accumulation of mercury, an increasing of pH, temperature, and EC; and a decreasing of ORP and DO.

At residence which also used as agricultural field the soils and groundwater was found with high mercury concentrations. Agriculture plays role to the changes of soil and groundwater properties. Agricultural soils were found with high mercury concentrations, a decreasing of pH and ORP, and a rising of EC, water percentage, and OMC. A decreasing of pH and DO, and an increasing of temperature, ORP, EC and salinity were found on groundwater system with agricultural above. The role of organic carbon to promote the acidification and to increase the microorganism

activity may generate problems related to mercury mobilization and transformation of mercury to be more hazardous substances.



## REFERENCES

1. Kelderman, P., et al., *Pollution assessment of the canal sediments in the city of Delft (the Netherlands)*. Water Research, 2000. **34**(3): p. 936-944.
2. WHO, *World Health Organization. Mercury in Drinking-water*. 2005.
3. Zahir, F., et al., *Low dose mercury toxicity and human health*. Environmental toxicology and pharmacology, 2005. **20**(2): p. 351-360.
4. Li, P., et al., *Human inorganic mercury exposure, renal effects and possible pathways in Wanshan mercury mining area, China*. Environmental research, 2015. **140**: p. 198-204.
5. Spiegel, S.J., *Governance institutions, resource rights regimes, and the informal mining sector: Regulatory complexities in Indonesia*. World Development, 2012. **40**(1): p. 189-205.
6. Anderson, C., *Assessment of biogeochemical mercury cycling: Sekotong artisanal mining area, Lombok, West Nusa Tenggara (WNT) Province, Indonesia. IDRF Final Report, CT File: GRA/347/7. .* 2010.
7. d'Aquino, L., et al., *Effect of some rare earth elements on the growth and lanthanide accumulation in different Trichoderma strains*. Soil Biology and Biochemistry, 2009. **41**(12): p. 2406-2413.
8. Xinde, C., W. Xiaorong, and Z. Guiwen, *Assessment of the bioavailability of rare earth elements in soils by chemical fractionation and multiple regression analysis*. Chemosphere, 2000. **40**(1): p. 23-28.
9. Zhang, S. and X.-q. Shan, *Speciation of rare earth elements in soil and accumulation by wheat with rare earth fertilizer application*. Environmental Pollution, 2001. **112**(3): p. 395-405.
10. Velásquez-López, P.C., et al., *Cyanidation of mercury-rich tailings in artisanal and small-scale gold mining: identifying strategies to manage environmental risks in Southern Ecuador*. Journal of Cleaner Production, 2011. **19**(9): p. 1125-1133.

11. Ismawati, Y., Petrlik, J., DiGangi, J., *Mercury Hotspots in Indonesia: ASGM sites: Poboaya and Sekotong in Indonesia IPEN Mercury-Free Campaign Report*. 2013.
12. Prasetyo, B., et al., *Rehabilitation of artisanal mining gold land in West Lombok, Indonesia: 2. Arbuscular mycorrhiza status of tailings and surrounding soils*. *Journal of Agricultural Science*, 2010. **2**(2): p. p202.
13. Male, Y.T., et al., *Recent mercury contamination from artisanal gold mining on Buru Island, Indonesia—Potential future risks to environmental health and food safety*. *Marine pollution bulletin*, 2013. **77**(1): p. 428-433.
14. Ning, L., et al., *Heavy metal pollution in surface water of Linglong gold mining area, China*. *Procedia Environmental Sciences*, 2011. **10**: p. 914-917.
15. Francis, M., *Background Report on Fertilizer Use, Contaminants and Regulators*. 2000: DIANE Publishing.
16. Zhao, X. and D. Wang, *Mercury in some chemical fertilizers and the effect of calcium superphosphate on mercury uptake by corn seedlings (Zea mays L.)*. *Journal of Environmental Sciences*, 2010. **22**(8): p. 1184-1188.
17. Mortvedt, J., *Heavy metal contaminants in inorganic and organic fertilizers*. *Fertilizer Research*, 1995. **43**(1-3): p. 55-61.
18. Meili, M., *The coupling of mercury and organic matter in the biogeochemical cycle—towards a mechanistic model for the boreal forest zone*. *Water Air & Soil Pollution*, 1991. **56**(1): p. 333-347.
19. Wongsasuluk, P., et al., *Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agricultural area in Ubon Ratchathani province, Thailand*. *Environmental geochemistry and health*, 2014. **36**(1): p. 169-182.
20. Buchhamer, E.E., et al., *Environmental risk assessment of arsenic and fluoride in the Chaco province, Argentina: Research advances*. *Journal of Toxicology and Environmental Health, Part A*, 2012. **75**(22-23): p. 1437-1450.
21. Gibbs, R.J., *Transport phases of transition metals in the Amazon and Yukon Rivers*. *Geological Society of America Bulletin*, 1977. **88**(6): p. 829-843.

22. Suesat, S., *Distribution and potential mobility of heavy metals in soil and shallow groundwater aquifer in an agricultural area: A case study of Hua Rua, Changwat Ubon Ratchathani*. . 2010.
23. Wongsasuluk, P., *Human health risk assessment associated with heavy metals in drinking shallow groundwater wells at Ubon Ratchathani province, Thailand*. 2010.
24. Xu, J., et al., *Influence of particle size distribution, organic carbon, pH and chlorides on washing of mercury contaminated soil*. *Chemosphere*, 2014. **109**: p. 99-105.
25. Ravichandran, M., *Interactions between mercury and dissolved organic matter—a review*. *Chemosphere*, 2004. **55**(3): p. 319-331.
26. Pannu, R., S.D. Siciliano, and N.J. O'Driscoll, *Quantifying the effects of soil temperature, moisture and sterilization on elemental mercury formation in boreal soils*. *Environmental Pollution*, 2014. **193**: p. 138-146.
27. Jing, Y., Z. He, and X. Yang, *Effects of pH, organic acids, and competitive cations on mercury desorption in soils*. *Chemosphere*, 2007. **69**(10): p. 1662-1669.
28. Schlüter, K., *Review: evaporation of mercury from soils. An integration and synthesis of current knowledge*. *Environmental Geology*, 2000. **39**(3-4): p. 249-271.
29. Barrow, N. and V. Cox, *The effects of pH and chloride concentration on mercury sorption. II. By a soil*. *Journal of Soil Science*, 1992. **43**(2): p. 305-312.
30. Yin, Y., et al., *Adsorption of mercury (II) by soil: effects of pH, chloride, and organic matter*. *Journal of Environmental Quality*, 1996. **25**(4): p. 837-844.
31. Gustin, M.S. and J. Stamenkovic, *Effect of watering and soil moisture on mercury emissions from soils*. *Biogeochemistry*, 2005. **76**(2): p. 215-232.
32. Pannu, R., Siciliano, S., O'Driscoll, N.J., *Canadian Mercury Science Assessment. Chapter 3. In: Factors Affecting Mercury Emissions from Canadian Soils (in press)*. 2014.

33. Marumoto, K. and S. Imai, *Determination of dissolved gaseous mercury in seawater of Minamata Bay and estimation for mercury exchange across air-sea interface*. Marine Chemistry, 2015. **168**: p. 9-17.
34. Briggs, C. and M.S. Gustin, *Building upon the conceptual model for soil mercury flux: evidence of a link between moisture evaporation and Hg evasion*. Water, Air, & Soil Pollution, 2013. **224**(10): p. 1-13.
35. Hintelmann, H. and R. Harris, *Application of multiple stable mercury isotopes to determine the adsorption and desorption dynamics of Hg (II) and MeHg to sediments*. Marine chemistry, 2004. **90**(1): p. 165-173.
36. Liang, P., et al., *A simulation study of mercury release fluxes from soils in wet-dry rotation environment*. Journal of Environmental Sciences, 2014. **26**(7): p. 1445-1452.
37. Randall, P.M. and S. Chattopadhyay, *Mercury contaminated sediment sites—An evaluation of remedial options*. Environmental research, 2013. **125**: p. 131-149.
38. He, Z., S.J. Traina, and L.K. Weavers, *Sonolytic desorption of mercury from aluminum oxide: effects of pH, chloride, and organic matter*. Environmental science & technology, 2007. **41**(3): p. 779-784.
39. Kim, C.S., J.J. Rytuba, and G.E. Brown, *EXAFS study of mercury (II) sorption to Fe- and Al-(hydr) oxides: II. Effects of chloride and sulfate*. Journal of colloid and interface science, 2004. **270**(1): p. 9-20.
40. Kozyatnyk, I., L. Lövgren, and P. Haglund, *On the leaching of mercury by brackish seawater from permeable barriers materials and soil*. Journal of Environmental Chemical Engineering, 2015. **3**(2): p. 1200-1206.
41. Rolffhus, K.R. and W.F. Fitzgerald, *The evasion and spatial/temporal distribution of mercury species in Long Island Sound, CT-NY*. Geochimica et Cosmochimica Acta, 2001. **65**(3): p. 407-418.
42. Nordberg, G.F., B.A. Fowler, and M. Nordberg, *Handbook on the Toxicology of Metals*. 2014: Academic Press.

43. Soerensen, A.L., et al., *Drivers of surface ocean mercury concentrations and air-sea exchange in the West Atlantic Ocean*. Environmental science & technology, 2013. **47**(14): p. 7757-7765.
44. [Internet], *Climate: Sekotong Timur*. <http://en.climate-data.org/location/563291/> (Accessed on 15th October 2014).
45. Parker, J.L. and N.S. Bloom, *Preservation and storage techniques for low-level aqueous mercury speciation*. Science of the Total Environment, 2005. **337**(1): p. 253-263.
46. Voegborlo, R. and H. Akagi, *Determination of mercury in fish by cold vapour atomic absorption spectrometry using an automatic mercury analyzer*. Food Chemistry, 2007. **100**(2): p. 853-858.
47. Eka, N., D. Heri, and A. Rohman, *Validation of mercury analyzer for determination of mercury in snake fruit*. International Food Research Journal, 2012. **19**(3): p. 933-936.
48. Simange, S.M., D. Simbolon, and D. Jusadi, *Analisis kandungan merkuri (HG) dan sianida (CN) pada beberapa jenis ikan hasil tangkapan nelayan di Teluk Kao, Halmahera utara*. 2011.
49. Suriansyah, A. and A. Gusrizal, *Alibrasi dan adisi standar pada pengukuran merkuri dalam air dengan kandungan senyawa organik tinggi menggunakan spektrofotometer serapan atom*. Jurnal Kimia Khatulistiwa, 2013. **1**(1).
50. Cohen, J., *Statistical power analysis for the behavioral sciences*. 1977: Academic press.
51. WHO, *World Health Organization. Guidelines for drinking-water quality: recommendations*. Vol. 1. 2004: World Health Organization.
52. (US.EPA), U.S.E.P.A., *Drinking Water Standards and Health Advisories Table*. 2007.
53. Arshad, M. and G. Coen, *Characterization of soil quality: physical and chemical criteria*. American Journal of Alternative Agriculture, 1992. **7**(1-2): p. 25-31.



54. Ekperusi, O.A. and I.F. Aigbodion, *Bioremediation of heavy metals and petroleum hydrocarbons in diesel contaminated soil with the earthworm: Eudrilus eugeniae*. SpringerPlus, 2015. **4**(1): p. 1-13.
55. Micó, C., et al., *Assessing heavy metal sources in agricultural soils of an European Mediterranean area by multivariate analysis*. Chemosphere, 2006. **65**(5): p. 863-872.
56. Schenkeveld, M., et al., *Seawater and brackish water desalination in the Middle East, North Africa and Central Asia*. World Bank, 2004.
57. de Jong, E.B., et al., *Changing water quality in the Middle Mahakam Lakes: water quality trends in a context of rapid deforestation, mining and palm oil plantation development in Indonesia's Middle Mahakam wetlands*. Wetlands, 2015. **35**(4): p. 733-744.
58. Gemici, Ü., *Evaluation of the water quality related to the acid mine drainage of an abandoned mercury mine (Alaşehir, Turkey)*. Environmental monitoring and assessment, 2008. **147**(1-3): p. 93-106.
59. NJDEP, *New Jersey Department of Environmental Protection. Site Remediation Program: Monitored Natural Attenuation Technical Guidance* 2012.
60. Bruynesteyn, A. and R. Hackl, *Evaluation of acid production potential of mining waste materials*. Minerals and the Environment, 1982. **4**(1): p. 5-8.
61. Mc Donald, K. and D.-W. Sun, *Effect of evacuation rate on the vacuum cooling process of a cooked beef product*. Journal of Food Engineering, 2001. **48**(3): p. 195-202.
62. Subramanian, V. and K. Saxena. *Hydrogeochemistry of groundwater in the Delhi region of India, relation of water quality and quantity*. in *Proceedings of the Hamberg symposium IAHS publication*. 1983.
63. Graham, M., R. Haynes, and J. Meyer, *Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa*. Soil biology and biochemistry, 2002. **34**(1): p. 93-102.



APPENDIX A

จุฬาลงกรณ์มหาวิทยาลัย  
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Table A1. Summary statistic of mercury concentrations and physicochemical properties of soils in 7 sampling locations of Tembowong village, Sekotong regency, Lombok Island, Indonesia

Parameter	Location	Min	Max	Mean	SE	Median	SD
Mercury (ug/L )	TE 1	0.008	0.014	0.012	0.002	0.013	0.003
	TE 2	0.020	0.102	0.051	0.026	0.031	0.045
	TE 3	0.018	0.048	0.028	0.010	0.019	0.017
	TE 4	0.021	0.034	0.028	0.004	0.029	0.007
	TE 5	0.894	1.277	1.068	0.112	1.033	0.194
	TE 6	0.566	0.776	0.649	0.065	0.604	0.112
	TE 7	0.010	0.028	0.020	0.005	0.023	0.009
pH	TE 1	7.47	7.62	7.56	0.05	7.59	0.08
	TE 2	7.64	8.26	7.93	0.18	7.88	0.31
	TE 3	7.64	8.08	7.84	0.13	7.80	0.22
	TE 4	7.66	7.72	7.69	0.02	7.68	0.03
	TE 5	7.76	7.78	7.77	0.01	7.77	0.01
	TE 6	7.69	8.04	7.87	0.10	7.87	0.18
	TE 7	7.34	7.43	7.38	0.03	7.36	0.05
Electrical conductivity (µs/cm)	TE 1	312.00	409	357.50	28.16	351.50	48.78
	TE 2	173.90	200	185.95	7.60	183.95	13.16
	TE 3	705	1153	879	138.66	779	240.16
	TE 4	97.90	157.60	127.75	17.23	127.75	29.85
	TE 5	180.05	202	190.05	6.41	188.10	11.10
	TE 6	274.50	304	284.50	9.75	275	16.89
	TE 7	167.30	325	244.15	45.57	240.15	78.93
Oxidation-Reduction Potential (mV)	TE 1	10.45	14.6	12.25	1.23	11.7	2.13
	TE 2	16	20.1	17.57	1.28	16.6	2.21
	TE 3	10.55	22.4	15.32	3.61	13	6.26
	TE 4	8.9	13.1	10.55	1.29	9.65	2.24
	TE 5	13.99	18.3	15.70	1.32	14.8	2.29
	TE 6	13.3	21.9	17.15	2.52	16.25	4.37
	TE 7	6.65	12.2	8.65	1.78	7.1	3.08
Water content (%)	TE 1	5.91	10.5	8.21	1.33	8.21	2.30
	TE 2	17.46	17.59	17.53	0.04	17.53	0.07
	TE 3	21.94	27.11	24.52	1.49	24.52	2.59
	TE 4	22.43	30.05	26.24	2.20	26.24	3.81
	TE 5	28.46	30.31	29.38	0.53	29.38	0.93
	TE 6	29.26	32.4	30.83	0.91	30.83	1.57
	TE 7	24.14	31.16	27.65	2.03	27.65	3.51
Organic Content (%)	TE 1	1.38	1.41	1.40	0.01	1.4	0.02
	TE 2	1.98	2.49	2.24	0.15	2.24	0.26
	TE 3	5.48	10.2	7.84	1.36	7.84	2.36
	TE 4	3.6	4.45	4.03	0.25	4.03	0.43
	TE 5	4.53	5.2	4.87	0.19	4.87	0.34
	TE 6	4.58	5.31	4.94	0.21	4.93	0.37
	TE 7	3.44	4.21	3.83	0.22	3.83	0.39

Table A2. Summary statistic of mercury concentrations and physicochemical properties of groundwater in 7 sampling locations of Tembawang village, Sekotong regency, Lombok Island, Indonesia

Parameter	Location	Min	Max	Mean	SE	Median	SD
Mercury ( $\mu\text{g/L}$ )	TE 1	0.030	0.067	0.042	0.012	0.030	0.021
	TE 2	0.030	0.140	0.073	0.034	0.049	0.059
	TE 3	0.042	0.063	0.054	0.006	0.056	0.011
	TE 4	0.049	0.091	0.068	0.012	0.063	0.021
	TE 5	0.030	0.328	0.166	0.087	0.140	0.151
	TE 6	0.035	0.070	0.049	0.011	0.042	0.018
	TE 7	0.030	0.286	0.115	0.085	0.030	0.148
pH	TE 1	7.50	7.60	7.55	0.03	7.55	0.05
	TE 2	6.00	6.15	6.05	0.05	6.00	0.09
	TE 3	6.00	6.10	6.05	0.03	6.05	0.05
	TE 4	6.00	6.15	6.05	0.05	6.00	0.09
	TE 5	6.00	6.20	6.10	0.06	6.10	0.10
	TE 6	5.80	6.00	5.90	0.06	5.90	0.10
	TE 7	6.40	6.60	6.50	0.06	6.50	0.10
Temperature ( $^{\circ}\text{C}$ )	TE 1	29.20	29.30	29.25	0.03	29.25	0.05
	TE 2	29.30	29.40	29.35	0.03	29.35	0.05
	TE 3	29.60	29.70	29.65	0.03	29.65	0.05
	TE 4	29.10	29.10	29.10	0.00	29.10	0.00
	TE 5	29.00	29.10	29.05	0.03	29.05	0.05
	TE 6	29.70	29.70	29.70	0.00	29.70	0.00
	TE 7	28.70	28.80	28.75	0.03	28.75	0.05
Electrical conductivity ( $\mu\text{S/cm}$ )	TE 1	628.00	632.00	630.00	1.15	630.00	2.00
	TE 2	719.00	720.00	719.50	0.29	719.50	0.50
	TE 3	644.00	644.00	644.00	0.00	644.00	0.00
	TE 4	625.50	629.00	627.50	1.04	628.00	1.80
	TE 5	514.00	515.00	514.50	0.29	514.50	0.50
	TE 6	521.80	523.00	522.50	0.36	522.70	0.62
	TE 7	766.00	773.00	769.50	2.02	769.50	3.50
Oxidation-Reduction Potential (mV)	TE 1	11.70	15.30	13.60	1.04	13.80	1.81
	TE 2	42.70	44.55	43.55	0.54	43.40	0.93
	TE 3	46.00	47.70	47.10	0.55	47.60	0.95
	TE 4	38.00	40.20	39.35	0.68	39.85	1.18
	TE 5	51.40	54.42	53.00	0.88	53.18	1.52
	TE 6	54.60	56.80	55.70	0.64	55.70	1.10
	TE 7	33.30	34.60	34.10	0.40	34.40	0.70
Dissolved Oxygen (mg/L)	TE 1	2.81	2.83	2.82	0.01	2.82	0.01
	TE 2	1.86	2.11	2.01	0.08	2.05	0.13
	TE 3	2.47	2.53	2.51	0.02	2.52	0.03
	TE 4	2.39	2.48	2.45	0.03	2.47	0.05
	TE 5	1.33	1.33	1.33	0.00	1.33	0.00
	TE 6	2.17	2.21	2.19	0.01	2.18	0.02
	TE 7	1.58	1.60	1.59	0.01	1.58	0.01
Salinity (%)	TE 1	0.05	0.05	0.05	0.00	0.05	0.00
	TE 2	0.00	0.00	0.00	0.00	0.00	0.00
	TE 3	0.20	0.20	0.20	0.00	0.20	0.00
	TE 4	0.10	0.10	0.10	0.00	0.10	0.00
	TE 5	0.10	0.10	0.10	0.00	0.10	0.00
	TE 6	0.05	0.05	0.05	0.00	0.05	0.00
	TE 7	0.15	0.20	0.17	0.01	0.17	0.02

Table A3. Summary statistic of mercury concentrations and physicochemical properties of soils in 7 sampling locations of Gawah Puduk village, Sekotong reGENCY, Lombok Island, Indonesia

Parameter	Location	Min	Max	Mean	SE	Median	SD
Mercury (ug/L )	GP1	0.086	0.126	0.106	0.012	0.106	0.020
	GP2	0.348	0.924	0.570	0.179	0.438	0.310
	GP3	0.017	0.026	0.022	0.003	0.022	0.005
	GP4	1.017	1.657	1.283	0.193	1.174	0.334
	GP5	0.262	0.992	0.522	0.236	0.311	0.408
	GP6	0.152	0.213	0.182	0.018	0.180	0.031
	GP7	0.033	0.120	0.063	0.029	0.036	0.049
pH	GP1	7.00	7.30	7.15	0.09	7.15	0.15
	GP2	6.40	6.60	6.50	0.06	6.50	0.10
	GP3	8.48	8.53	8.51	0.02	8.52	0.03
	GP4	8.40	8.73	8.55	0.10	8.51	0.17
	GP5	9.05	9.19	9.12	0.04	9.12	0.07
	GP6	8.01	8.81	8.36	0.24	8.26	0.41
	GP7	8.12	8.16	8.14	0.01	8.13	0.02
Electrical conductivity (µs/cm)	GP1	307.00	396	346.50	26.17	336.50	45.33
	GP2	105.80	257	181.40	43.65	181.40	75.60
	GP3	450	592	519	41.07	514	71.13
	GP4	1210.05	1463.00	1312.05	77.01	1263.10	133.39
	GP5	304.00	475	378.00	50.69	355.00	87.79
	GP6	370.00	376	373.00	1.73	373	3.00
	GP7	511.50	814	614.50	99.77	518.00	172.80
Oxidation-Reduction Potential (mV)	GP1	-39.1	-22.4	-31.1	4.83	-31.8	8.37
	GP2	-10.8	-8.4	-9.4	0.72	-9	1.25
	GP3	-41.85	-32.9	-37.65	2.60	-38.2	4.50
	GP4	-57	-40	-50.6	5.34	-54.8	9.25
	GP5	-70.15	-59.6	-65.95	3.23	-68.1	5.59
	GP6	-53.4	-24.8	-41.2	8.52	-45.4	14.76
	GP7	5.35	5.6	5.45	0.08	5.4	0.13
Water content (%)	GP1	27.5	30.35	28.92	0.82	28.92	1.43
	GP2	24.65	39.75	32.20	4.36	32.19	7.55
	GP3	17.92	19.63	18.78	0.49	18.79	0.86
	GP4	42.56	42.91	42.74	0.10	42.76	0.18
	GP5	28.17	30.27	29.22	0.61	29.22	1.05
	GP6	37.54	39.23	38.38	0.49	38.38	0.85
	GP7	12.13	14.84	13.48	0.78	13.48	1.36
Organic Content (%)	GP1	4.45	4.77	4.61	0.09	4.62	0.16
	GP2	2.52	3.64	3.08	0.32	3.08	0.56
	GP3	3.08	3.09	3.08	0.00	3.08	0.01
	GP4	3.68	3.78	3.74	0.03	3.75	0.05
	GP5	3.04	3.24	3.14	0.06	3.15	0.10
	GP6	2.90	2.98	2.94	0.02	2.93	0.04
	GP7	1.25	1.26	1.25	0.00	1.25	0.01

Table A4. Summary statistic of mercury concentrations and physicochemical properties of groundwater in 7 sampling locations of Gawah Puduk village, Sekotong regency, Lombok Island, Indonesia

Parameter	Location	Min	Max	Mean	SE	Median	SD
Mercury (ug/L )	GP1	0.105	0.126	0.114	0.006	0.112	0.011
	GP2	0.030	0.035	0.032	0.002	0.030	0.003
	GP3	0.049	0.084	0.070	0.011	0.077	0.018
	GP4	1.320	3.568	2.370	0.653	2.221	1.132
	GP5	0.084	0.335	0.170	0.083	0.091	0.143
	GP6	0.030	0.084	0.064	0.017	0.077	0.029
	GP7	0.030	0.035	0.032	0.002	0.030	0.003
pH	GP1	7.80	8.00	7.90	0.06	7.90	0.10
	GP2	7.10	7.10	7.10	0.00	7.10	0.00
	GP3	7.30	7.40	7.35	0.03	7.35	0.05
	GP4	7.20	7.35	7.25	0.05	7.20	0.09
	GP5	7.40	7.50	7.45	0.03	7.45	0.05
	GP6	7.20	7.35	7.25	0.05	7.20	0.09
	GP7	6.40	6.60	6.50	0.06	6.50	0.10
Temperature (°C)	GP1	29.70	29.70	29.70	0.00	29.70	0.00
	GP2	29.20	29.50	29.35	0.09	29.35	0.15
	GP3	28.80	28.90	28.85	0.03	28.85	0.05
	GP4	29.30	29.30	29.30	0.00	29.30	0.00
	GP5	28.80	28.80	28.80	0.00	28.80	0.00
	GP6	29.00	29.00	29.00	0.00	29.00	0.00
	GP7	29.30	29.30	29.30	0.00	29.30	0.00
Electrical conductivity (µs/cm)	GP1	879.30	879.70	879.50	0.12	879.50	0.20
	GP2	835.00	836.00	835.50	0.29	835.50	0.50
	GP3	929.50	934.50	932.00	1.44	932.00	2.50
	GP4	2440.00	2440.00	2440.00	0.00	2440.00	0.00
	GP5	1692.00	1709.00	1701.00	4.93	1702.00	8.54
	GP6	1343.00	1360.00	1351.00	4.93	1350.00	8.54
	GP7	893.50	908.00	900.50	4.19	900.00	7.26
Oxidation-Reduction Potential (mV)	GP1	16.10	17.10	16.65	0.29	16.75	0.51
	GP2	6.31	7.10	6.71	0.23	6.71	0.40
	GP3	28.77	29.40	29.15	0.19	29.28	0.33
	GP4	35.50	36.00	35.80	0.15	35.90	0.26
	GP5	25.58	27.30	26.50	0.50	26.62	0.87
	GP6	35.30	38.50	36.90	0.92	36.90	1.60
	GP7	21.90	25.60	24.20	1.16	25.10	2.01
Dissolved Oxygen (mg/L)	GP1	1.20	1.23	1.22	0.01	1.22	0.02
	GP2	1.43	1.49	1.46	0.02	1.47	0.03
	GP3	1.60	1.76	1.66	0.05	1.62	0.09
	GP4	1.42	1.44	1.43	0.01	1.44	0.01
	GP5	1.73	1.79	1.76	0.02	1.75	0.03
	GP6	0.56	0.58	0.57	0.01	0.56	0.01
	GP7	1.02	1.05	1.04	0.01	1.04	0.02
Salinity (%)	GP1	1.00	1.00	1.00	0.00	1.00	0.00
	GP2	0.50	0.50	0.50	0.00	0.50	0.00
	GP3	0.50	0.50	0.50	0.00	0.50	0.00
	GP4	2.00	3.00	2.50	0.29	2.50	0.50
	GP5	2.00	2.00	2.00	0.00	2.00	0.00
	GP6	1.00	2.00	1.50	0.29	1.50	0.50
	GP7	0.50	0.50	0.50	0.00	0.50	0.00

Table A5. Summary statistic of mercury concentrations and physicochemical properties of river water in 6 sampling locations of Merebek river, Sekotong regency, Lombok Island, Indonesia

Parameter	Location	Min	Max	Mean	SD	SE	Median
Mercury concentrations (ug/L)	R1	0.042	0.105	0.070	0.032	0.018	0.063
	R2	0.168	0.629	0.379	0.233	0.134	0.342
	R3	0.112	0.810	0.410	0.360	0.208	0.307
	R4	0.126	0.196	0.161	0.035	0.020	0.161
	R5	0.265	0.531	0.405	0.133	0.077	0.419
	R6	1.034	2.305	1.764	0.657	0.379	1.955
pH	R1	6.40	7.00	6.70	0.30	0.17	6.70
	R2	7.10	7.10	7.10	0.00	0.00	7.10
	R3	6.80	7.20	6.93	0.23	0.13	6.80
	R4	6.80	7.20	6.97	0.21	0.12	6.90
	R5	7.10	7.30	7.20	0.10	0.06	7.20
	R6	7.00	7.20	7.13	0.12	0.07	7.20
Temperature	R1	30.60	31.10	30.80	0.26	0.15	30.70
	R2	31.00	31.20	31.10	0.10	0.06	31.10
	R3	31.40	32.40	31.77	0.55	0.32	31.50
	R4	30.50	31.40	30.80	0.52	0.30	30.50
	R5	32.70	33.30	32.97	0.31	0.18	32.90
	R6	32.50	32.90	32.70	0.20	0.12	32.70
Electrical conductivity ( $\mu$ S/cm)	R1	564	687	616.7	63.4	36.6	599.0
	R2	588	599	593.7	5.5	3.2	594.0
	R3	440	443	441.7	1.5	0.9	442.0
	R4	188.6	195.2	191.4	3.4	2.0	190.5
	R5	457	474	463.0	9.5	5.5	458.0
	R6	29,290.0	35,800.0	33,230.0	3,464.5	2,000.2	34,600.0
Oxidation-Reduction Potential (mV)	R1	-15.40	-13.20	-14.47	1.14	0.66	-14.80
	R2	-33.80	-21.90	-28.47	6.05	3.49	-29.70
	R3	-5.60	-1.60	-3.40	2.03	1.17	-3.00
	R4	-10.50	-8.50	-9.63	1.03	0.59	-9.90
	R5	-20.30	-14.00	-18.07	3.53	2.04	-19.90
	R6	-38.40	-33.30	-35.93	2.55	1.47	-36.10
Dissolved Oxygen (mg/L)	R1	4.25	4.34	4.30	0.05	0.03	4.32
	R2	4.14	4.48	4.29	0.17	0.10	4.25
	R3	3.71	4.12	3.90	0.21	0.12	3.87
	R4	4.45	4.63	4.56	0.10	0.06	4.61
	R5	4.41	4.58	4.49	0.09	0.05	4.47
	R6	4.04	4.27	4.18	0.13	0.07	4.24
Salinity (%)	R1	0	0	0	0	0	0
	R2	0	0	0	0	0	0
	R3	0	0	0	0	0	0
	R4	0	0	0	0	0	0
	R5	0	0	0	0	0	0
	R6	2	2	2	0	0	2

Note: R1 and R2 are located at Tembowong village site; R4 and R5 located at Gawah Puduk site; R1 and R4 refer to upper site; R2, R3, and R5 refer to middle zone; and R6 refers to estuary zone

Table A6. Mercury calibration with water matrices (IKU/5.4/MA-01)

No	Concentration (ug/L )	Abs (Average)
1	0.05	0.0008
2	0.10	0.0023
3	0.20	0.0047
4	0.40	0.0079
5	0.80	0.0166
6	1.60	0.0286
7	3.20	0.0580

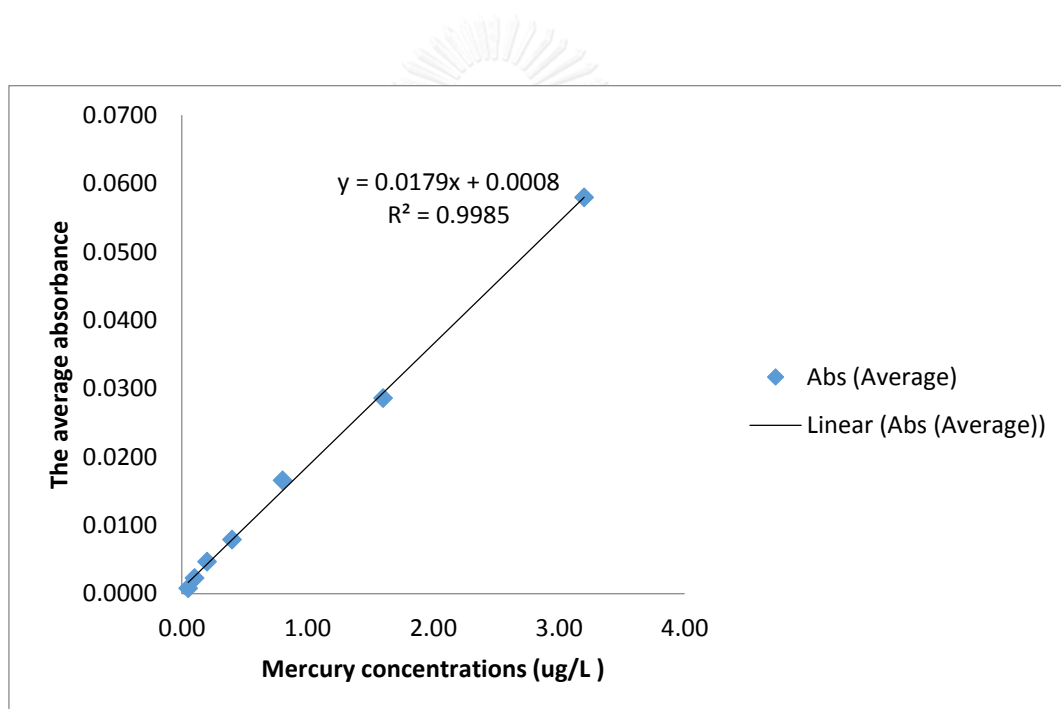


Figure A1. Mercury calibration in water matrices



Table A7. Mercury calibration with soil matrices (IKU/5.4/MA-05)

No	Concentration (ug/L )	Abs (Average)
1	0.05	0.0021
2	0.10	0.0036
3	0.20	0.0069
4	0.40	0.0121
5	0.80	0.0230
6	1.60	0.0410
7	3.20	0.0835

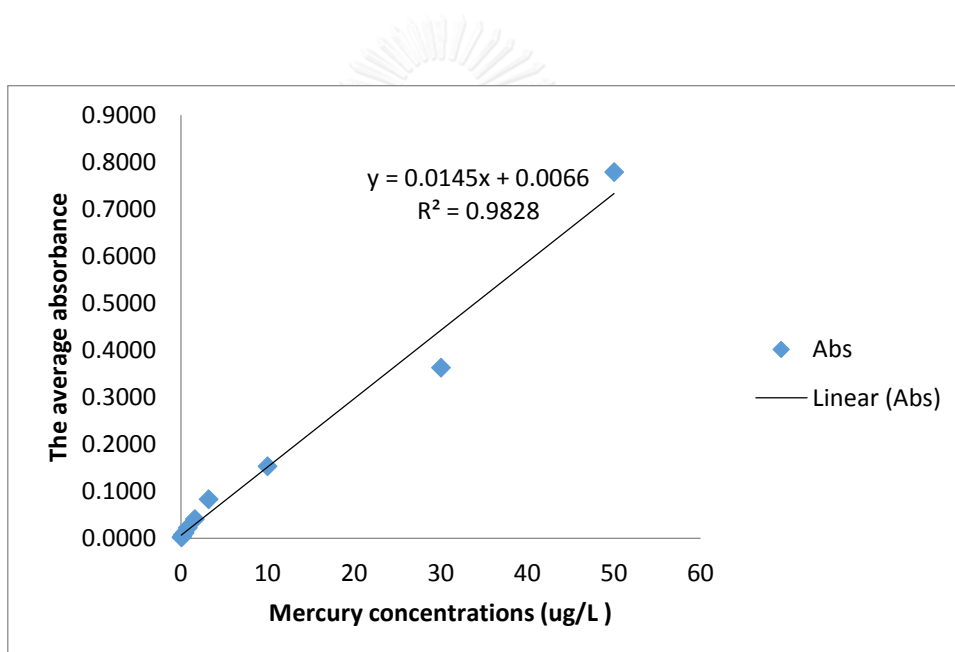



Figure A2. Mercury calibration in soil matrices



  
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**Letter of Certification**  
Number : 11.07/LPPT-UGM/III/2015

This letter is certified by,

Name : Dr. Arief Nurrochmad, M.Si, M.Sc., Apt.  
NIP : 19770120 200501 1 001  
Position : Technical Manager and Research Coordination of LPPT UGM

State that

Name : Doni Marisi Sinaga  
NIM : 568 76560 20  
Institution : International Program in Hazardous Substance and Environmental Management, Graduate School, Chulalongkorn University

Has accomplished his research in Laboratorium Penelitian dan Pengujian Terpadu (LPPT), Universitas Gadjah Mada Yogyakarta, Indonesia during January-February 2015 (SPK 1939.222.15). Under supervision Heri Dwi Harmono and Mey Catur Alfiani, with title :

*“Mercury Contamination in Residence Area Resulting Small-scale Gold Extraction Operations in Sekotong Regency, Lombok, Indonesia”.*

To accomplish this research, these following accredited specifications and methods have been used :

1. Mercury analyzer that connected to the reaction unit of the Lab Analyzer 254, for
  - a) Water samples (IKU/5- 4//MA-01)
  - b) Soil samples (IKU/5.4/MA-05)
2. Fourier Transform Infrared Spectroscopy (FTIR)

This certification has been issued as any appropriate purposes.

Yogyakarta, March 12<sup>th</sup>, 2015  
Technical Manager  
and Research Coordination of LPPT UGM


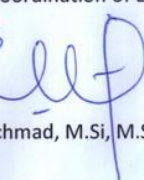


  
  
Dr. Arief Nurrochmad, M.Si, M.Sc., Apt.

Figure B1. Certification for research accomplishment from LPPT-UGM

  
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$y = 0,0179x + 0,0008$

Water Sample Points	Abs	Hg Concentration read on Mercury Analyzer ( $\mu\text{g/L}$ )	Volume of Dillution (mL)	Volume of sampel (mL)	Hg Total (ppb)	Average of Hg Total (ppb)	SD of Hg Total (ppb)
T11	0,0012	0,022346369	25	20	0,0279	0,0363	0,02751078
T12	0,0010	0,011173184	25	20	0,0140		
T13	0,0020	0,067039106	20	20	0,0670		
T21	0,0012	0,022346369	25	20	0,0279	0,0722	0,05939176
T22	0,0015	0,039106145	25	20	0,0489		
T23	0,0028	0,111731844	25	20	0,1397		
T31	0,0017	0,05027933	25	20	0,0628	0,0535	0,01066708
T32	0,0016	0,044692737	25	20	0,0559		
T33	0,0014	0,033519553	25	20	0,0419		
T41	0,0015	0,039106145	25	20	0,0489	0,0675	0,02133415
T42	0,0021	0,072625698	25	20	0,0908		
T43	0,0017	0,05027933	25	20	0,0628		
T51	0,0028	0,111731844	25	20	0,1397	0,1653	0,15176837
T52	0,0012	0,022346369	25	20	0,0279		
T53	0,0055	0,262569832	25	20	0,3282		
T61	0,0014	0,033519553	25	20	0,0419	0,0489	0,01847592
T62	0,0013	0,027932961	25	20	0,0349		
T63	0,0018	0,055865922	25	20	0,0698		
T71	0,0009	0,005586592	25	20	0,0070	0,1024	0,15929341
T72	0,0049	0,229050279	25	20	0,2863		
T73	0,0010	0,011173184	25	20	0,0140		
G11	0,0024	0,089385475	25	20	0,1117	0,1141	0,01066708
G12	0,0023	0,083798883	25	20	0,1047		
G13	0,0026	0,100558659	25	20	0,1257		
G21	0,0009	0,005586592	25	20	0,0070	0,0163	0,0161271
G22	0,0013	0,027932961	25	20	0,0349		
G23	0,0007	0,005586592	25	20	0,0070		
G31	0,0019	0,061452514	25	20	0,0768	0,0698	0,01847592
G32	0,0020	0,067039106	25	20	0,0838		
G33	0,0015	0,039106145	25	20	0,0489		
G41	0,0197	1,055865922	25	20	1,3198	2,3696	1,13167999
G42	0,0326	1,776536313	25	20	2,2207		
G43	0,0519	2,854748603	25	20	3,5684		
G51	0,0056	0,268156425	25	20	0,3352	0,1699	0,14317062
G52	0,0021	0,072625698	25	20	0,0908		
G53	0,0020	0,067039106	25	20	0,0838		
G61	0,0020	0,067039106	25	20	0,0838	0,0582	0,03846069
G62	0,0010	0,011173184	25	20	0,0140		
G63	0,0019	0,061452514	25	20	0,0768		



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Figure B2. Concentration results of water samples




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$y = 0,0179x + 0,0008$

Water Sample Points	Abs	Hg Concentration read on Mercury Analyzer ( $\mu\text{g/L}$ )	Volume of Dillution (mL)	Volume of sampel (mL)	Hg Total (ppb)	Average of Hg Total (ppb)	SD of Hg Total (ppb)
G71	0,0009	0,005586592	25	20	0,0070	0,0186	0,01453677
G72	0,0010	0,011173184	25	20	0,0140		
G73	0,0013	0,027932961	25	20	0,0349	0,0698	0,03200123
R11	0,0023	0,083798883	25	20	0,1047		
R12	0,0017	0,05027933	25	20	0,0628		
R13	0,0014	0,033519553	25	20	0,0419	0,3794	0,23269319
R21	0,0098	0,502793296	25	20	0,6285		
R22	0,0057	0,273743017	25	20	0,3422		
R23	0,0032	0,134078212	25	20	0,1676	0,4097	0,36025218
R31	0,0066	0,324022346	50	20	0,8101		
R32	0,0016	0,044692737	50	20	0,1117		
R33	0,0030	0,122905028	50	20	0,3073	0,1606	0,0349162
R41	0,0031	0,12849162	25	20	0,1606		
R42	0,0026	0,100558659	25	20	0,1257		
R43	0,0036	0,156424581	25	20	0,1955	0,4050	0,13323173
R51	0,0038	0,167597765	50	20	0,4190		
R52	0,0027	0,106145251	50	20	0,2654		
R53	0,0046	0,212290503	50	20	0,5307	1,7644	0,65662266
R61	0,0082	0,413407821	50	20	1,0335		
R62	0,0148	0,782122905	50	20	1,9553		
R63	0,0173	0,921787709	50	20	2,3045		

Figure B3. Concentration results of water samples ..... (continue)




  
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$y = 0,0145x + 0,0066$

Soil Sample Points	Abs	Hg Concentration read on Mercury Analyzer ( $\mu\text{g/L}$ )	Volume of Dillution (L)	Wet weight of sampel(g)	Hg Total (mg) per kg of soil	Average of Hg Total (mg) per kg of soil	SD of Hg Total (mg) per kg of soil
T11	0,0115	0,337931034	0,025	1	0,008	0,012	0,002947889
T12	0,0146	0,551724138	0,025	1	0,014		
T13	0,0143	0,531034483	0,025	1	0,013		
T21	0,0247	1,248275862	0,025	1	0,031	0,051	0,044561878
T22	0,0181	0,793103448	0,025	1	0,020		
T23	0,0658	4,082758621	0,025	1	0,102		
T31	0,0173	0,737931034	0,026	1	0,019	0,028	0,017301394
T32	0,0326	1,793103448	0,027	1	0,048		
T33	0,0169	0,710344828	0,025	1	0,018		
T41	0,0264	1,365517241	0,025	1	0,034	0,028	0,00679742
T42	0,0186	0,827586207	0,025	1	0,021		
T43	0,0235	1,165517241	0,025	1	0,029		
T51	0,5053	34,39310345	0,026	1	0,894	1,068	0,193874648
T52	0,7189	49,12413793	0,026	1	1,277		
T53	0,5829	39,74482759	0,026	1	1,033		
T61	0,4396	29,86206897	0,026	1	0,776	0,649	0,112114907
T62	0,3436	23,24137931	0,026	1	0,604		
T63	0,3222	21,76551724	0,026	1	0,566		
T71	0,0126	0,413793103	0,025	1	0,010	0,021	0,009138473
T72	0,0202	0,937931034	0,025	1	0,023		
T73	0,0228	1,117241379	0,025	1	0,028		
G11	0,0562	3,420689655	0,025	1	0,086	0,106	0,020091201
G12	0,0795	5,027586207	0,025	1	0,126		
G13	0,0683	4,255172414	0,025	1	0,106		
G21	0,2085	13,92413793	0,025	1	0,348	0,570	0,309852739
G22	0,5425	36,95862069	0,025	1	0,924		
G23	0,2605	17,51034483	0,025	1	0,438		
G31	0,0164	0,675862069	0,025	1	0,017	0,022	0,004747906
G32	0,0219	1,055172414	0,025	1	0,026		
G33	0,0194	0,882758621	0,025	1	0,022		
G41	0,5529	37,67586207	0,027	1	1,017	1,283	0,333209675
G42	0,9674	66,26206897	0,025	1	1,657		
G43	0,6613	45,15172414	0,026	1	1,174		
G51	0,5822	39,69655172	0,025	1	0,992	0,522	0,40834016
G52	0,1872	12,45517241	0,025	1	0,311		
G53	0,1583	10,46206897	0,025	1	0,262		
G61	0,1302	8,524137931	0,025	1	0,213	0,182	0,03072128

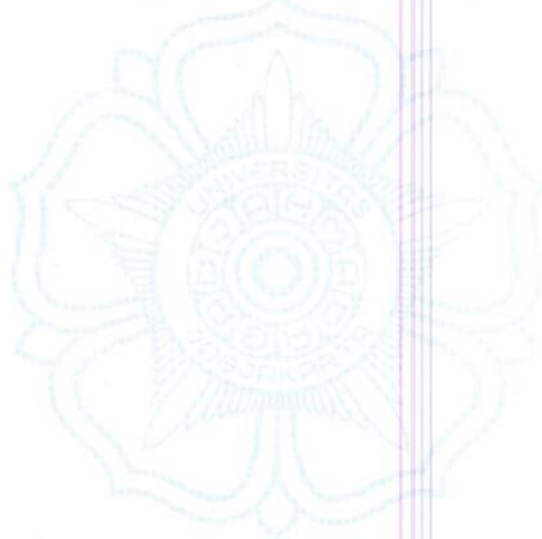
Figure B4. Concentration results of soil samples

  
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$y = 0,0145x + 0,0066$

Soil Sample Points	Abs	Hg Concentration read on Mercury Analyzer ( $\mu\text{g/L}$ )	Volume of Dillution (L)	Wet weight of sampel(g)	Hg Total (mg) per kg of soil	Average of Hg Total (mg) per kg of soil	SD of Hg Total (mg) per kg of soil
G62	0,1110	7,2	0,025	1	0,180		
G63	0,0946	6,068965517	0,025	1	0,152		
G71	0,0242	1,213793103	0,027	1	0,033	0,063	0,049696315
G72	0,0713	4,462068966	0,027	1	0,120		
G73	0,0260	1,337931034	0,027	1	0,036		







Figure B5. Concentration results of soil samples ..... (continue)

APPENDIX C  
Method Validation






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RDP/5.4.4/LPPT  
Rev 1

**Validasi Metode**  
**Analisis Kadar Mercury (Hg) dalam Tanah**

Uji linieritas dan kisaran linier

No	konsentrasi (ppb)	Absorbansi	Absorbansi rata-rata	Persamaan Regresi Linier $Y = bx + a$
1	0,05	0,0020	0,002	$b = 0,0255$ $a = 0,0014$ $r = 0,9992$
		0,0018		
		0,0024		
2	0,1	0,0032	0,004	
		0,0033		
		0,0044		
3	0,2	0,0081	0,007	
		0,0067		
		0,0058		
4	0,4	0,0125	0,012	
		0,0120		
		0,0117		
5	0,8	0,0240	0,023	
		0,0219		
		0,0232		
6	1,6	0,0394	0,041	
		0,0413		
		0,0423		
7	3,2	0,0843	0,083	
		0,0809		
		0,0852		

**Kesimpulan :**  
 Metode yang dikembangkan linier pada konsentrasi 0,05 sampai 3,2 ppb dengan nilai  $r = 0,9992$

Figure C1. Method validation of mercury measurement for soil samples: Linearity test

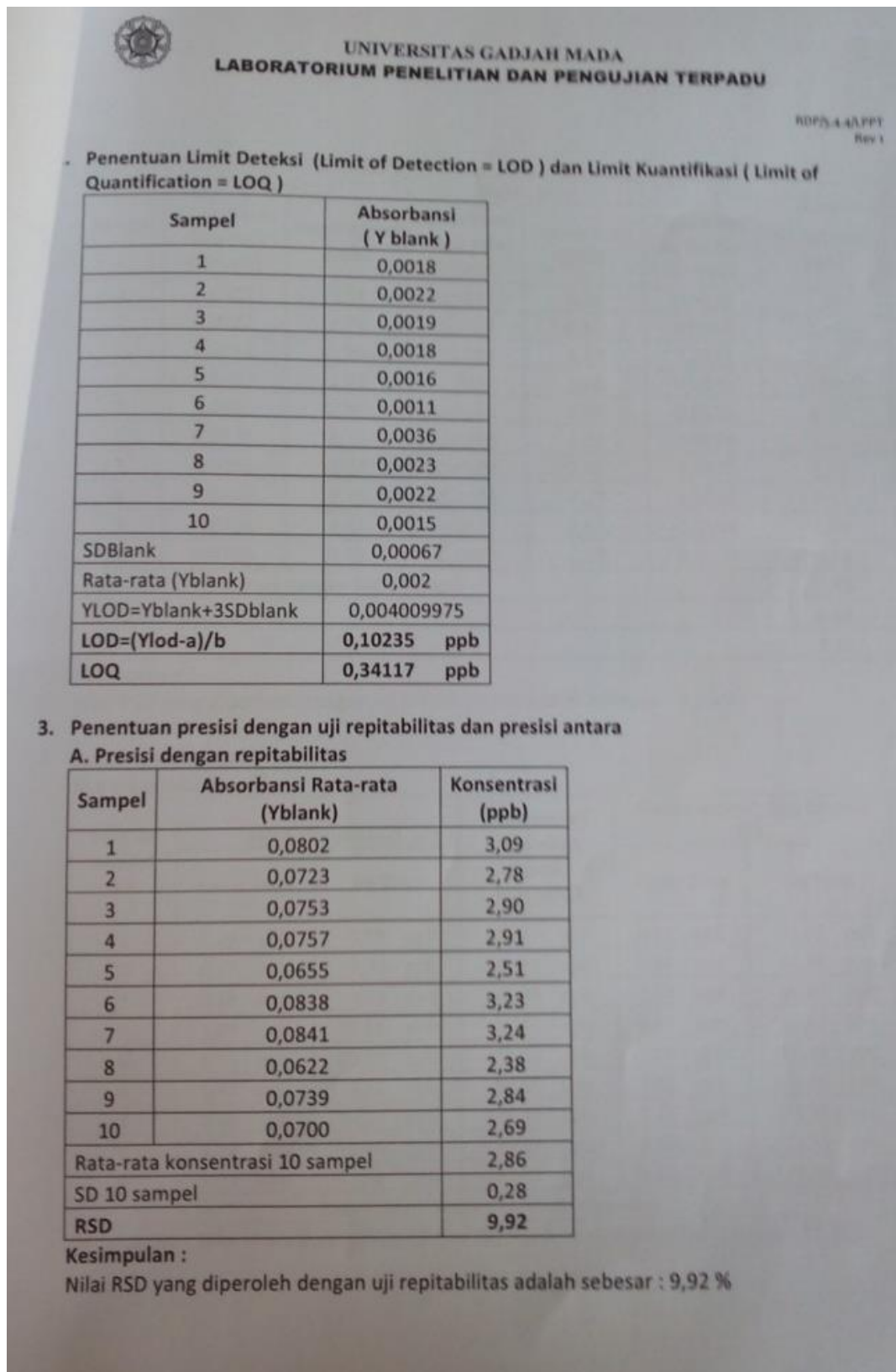


Figure C2. Method validation of mercury measurement for soil samples: LOD and LOQ test, and precision test

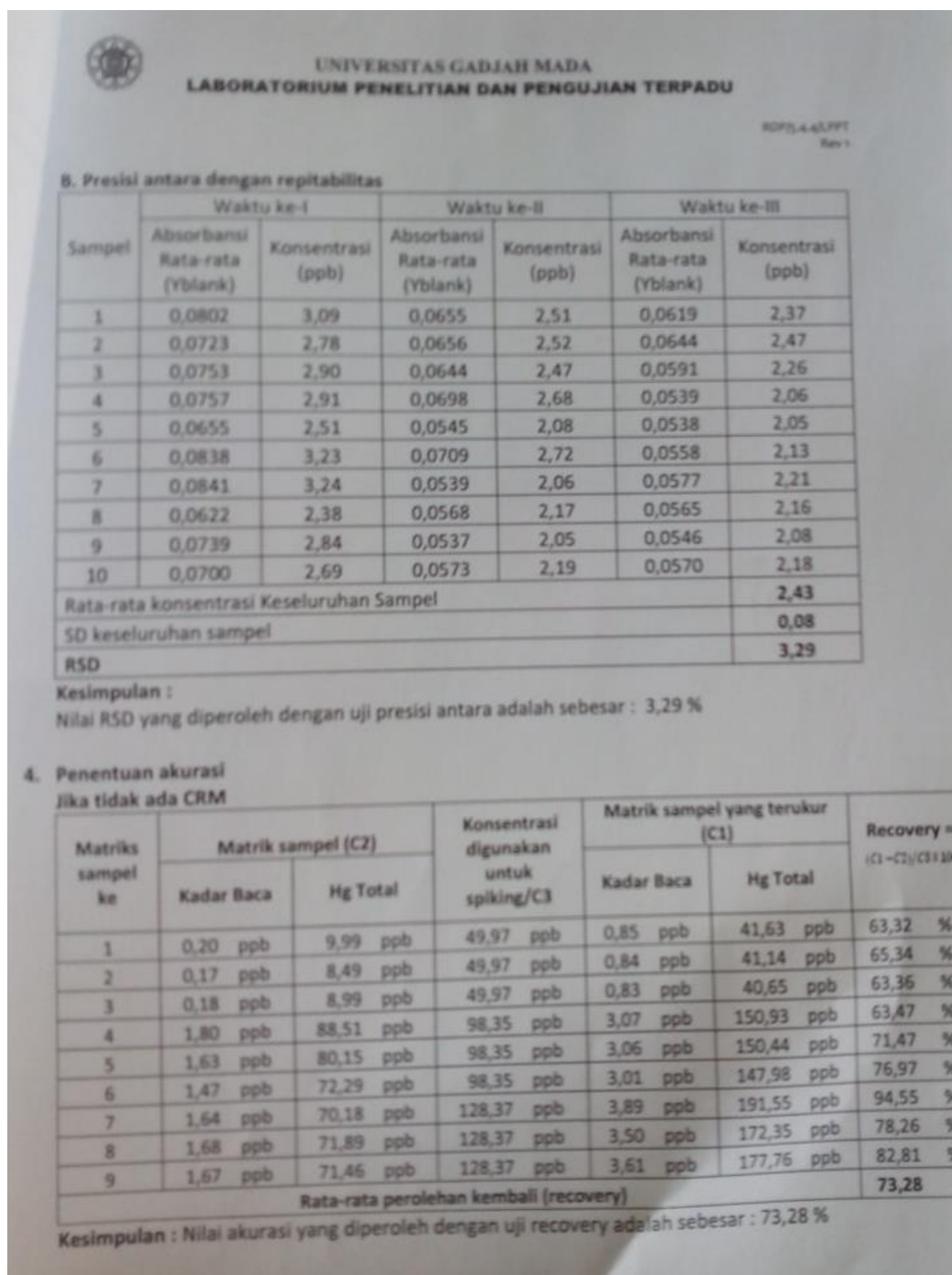



Figure C3. Method validation of mercury measurement for soil samples: and precision test with replication and accuracy (% recovery) test

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	LABORATORIUM PENELITIAN DAN PENGUJIAN TERPADU		
	DATA VERIFIKASI		
Hg TERLARUT DALAM AIR PERMUKAAN			

**VERIFIKASI Hg TERLARUT DALAM AIR PERMUKAAN**  
IKU/5.4/MA-01

1. Penentuan LOD dan LOQ Metode  
Konsentrasi analit terkecil yang masih memberikan hasil pengukuran adalah 0,05 ppb. Sepuluh blanko dan sepuluh blanko dispiking sehingga didapat konsentrasi Hg 0,05 ppb (sampel) diukur dengan metode uji.  
Hasil pembacaan absorbansi kesepuluh blanko dan sampel serta perhitungan LOD dan LOQ adalah :

No	Absorbansi blanko (yblank)	Absorbansi sampel (ysampel)
1	0,0006	0,0008
2	0,0004	0,0009
3	0,0006	0,0009
4	0,0004	0,0008
5	0,0004	0,0015
6	0,0005	0,0008
7	0,0004	0,0015
8	0,0006	0,0014
9	0,0005	0,0012
10	0,0005	0,0009
Rata-rata (ya)	0,00049	
SD (Sb)		0,000298329
3Sb		0,000894986
10 Sb		0,002983287
yLOD = 3Sb + ya		0,001384986
<b>LOD (ppb)</b>		<b>0,03</b>
yLOQ = 10Sb + ya		0,003473287
<b>LOQ (ppb)</b>		<b>0,10</b>




Pengesahan	Dibuat oleh	Diperiksa oleh	Disahkan oleh
Nama	Heri Dwi Harmono	Bambang Sutriyanto	Tri Joko Raharjo
Tanda Tangan			
Tanggal	21/09/10	23/09/10	24/09/10

Figure C4 Method validation of mercury measurement for water samples: LOD and LOQ test

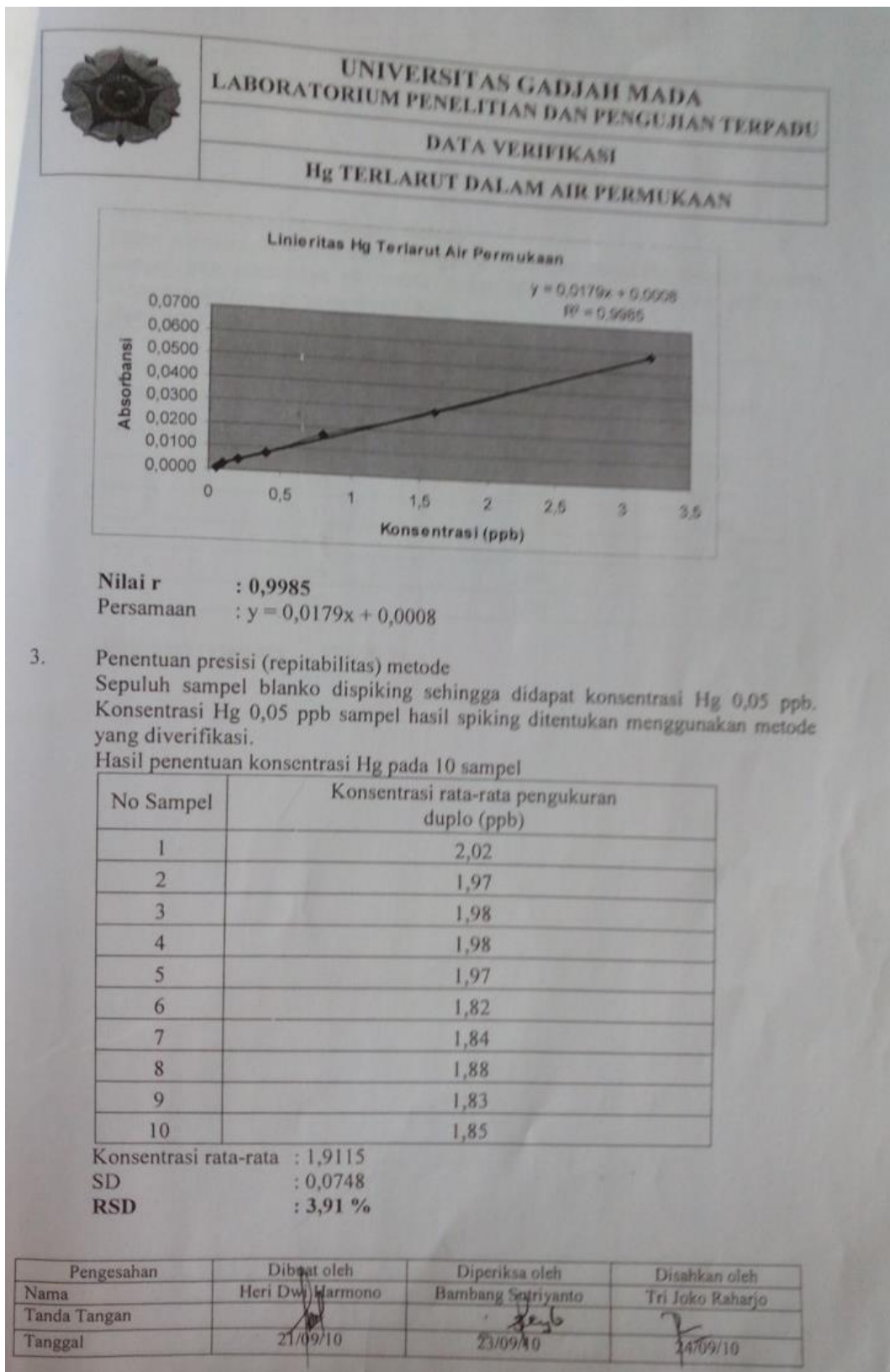



Figure C5 Method validation of mercury measurement for water samples: Linearity and precision test



	<b>UNIVERSITAS GADJAH MADA</b>		
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	<b>DATA VERIFIKASI</b>		
<b>Hg TERLARUT DALAM AIR PERMUKAAN</b>			

4. Penentuan rekovery (uji akurasi) metode  
Enam matriks sample dispiking sehingga didapat konsentrasi Hg 0,05 ppb. Keenam sampel dan blankonya (6 matrik tanpa spiking) ditentukan kandungan Hg menggunakan metode yang diverifikasi.  
Hasil penentuan konsentrasi 6 sampel dan recoverinya :

No Sampel	Konsentrasi rata-rata matriks tanpa spiking, pengukuran duplo (ppb)	Konsentrasi rata-rata matriks tanpa spiking, pengukuran duplo (ppb)	% Recoveri
1	0,01	1,00	101,00
2	0,00	0,96	96,00
3	0,01	1,00	101,00
4	0,02	1,01	103,00
5	0,06	1,09	115,00
6	0,02	1,00	102,00

**Rekovery rata-rata : 103,00 %**




Pengesahan	Dibuat oleh	Diperiksa oleh	Disahkan oleh
Nama	Heri Dwi Harmono	Bambang Sutriyanto	Tri Joko Raharjo
Tanda Tangan			
Tanggal	21/09/10	23/09/10	24/09/10

Figure C6 Method validation of mercury measurement for water samples: accuracy (% recovery) test

## VITA

After graduated from Faculty of Biology, Universitas Gadjah Mada, Indonesia, in 2012, Doni continued his career with working in security card industry for 1 year. During his period studying in Environmental Hazardous Waste Management, Chulalongkorn University, Thailand, he joined as an active member in Indonesian Student Association in Thailand, named PERMITHA, and contribute as an executive secretary and in Sponsorship department for International Conference and Seminar.

